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EDMUND H. FULLING

Edited by

DAVID J. ROGERS

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Utilization Abstracts

Book Reviews

Economic Botany of the Cycads

Cycads are used mainly as sources of food starch, particularly during periods of shortage of regular supplies. Aside from the use as food, some species are used as decorative plants, as minor sources of gums, fibers, and possibly oils. This work reviews most of the scattered literature on the uses of seven of the nine genera of the Cycadaceae, excluding Zamia *and* Ceratozamia.

JOHN W. THIERET
Chicago Natural History Museum

Introduction

Cycads are palmlike or fernlike plants that appear to be unrelated to any other group of living plants, although they are traditionally placed with the gymnosperms. In geologic times cycads were numerous and widely distributed. At present there remains but a single family, Cycadaceae, with nine genera and about 100 species, confined to the tropics and subtropics. These genera, their approximate distribution, and an estimate of the number of species each contains are as follows.

Cycas: ranging from northern and northeastern Australia, New Caledonia, Samoa and Fiji north and west to the Ryukyu Islands, southern China, the Philippines, Indo-China, Thailand, Malaya, Indonesia, Burma, India, Ceylon, and Madagascar. About twenty species.

Encephalartos: ranging from Union of South Africa, Mozambique, Southern Rhodesia, and northeast Angola north to Kenya, southwest Sudan, Haut Chari, and Ghana. About twenty species.

Stangeria: eastern coastal region of South Africa (Natal and adjacent Cape of Good Hope). One species.

Bowenia: northeastern Queensland, Australia. Two species.

Macrozamia: eastern, central, and southwestern Australia. About sixteen species.

Ceratozamia: southern Mexico and Guatamala. About six species.

Dioon: southern Mexico and Honduras. About six species.

Microcycas: Pinar del Rio, Cuba. One species.

Zamia: Florida, West Indies, southern Mexico south to Brazil and Chile. About thirty species.

The starch-rich stem of cycads may be either aerial or columnar, as in *Macrozamia reidlei* (Fig. 1), or subterranean and tuberous, as in *Macrozamia spiralis* (Fig. 2). In either case it is surmounted by a crown of pinnate or bipinnate (in *Bowenia*) leaves. Cycads are usually unbranched, although branching does occur occasionally. The tallest cycads are *Macrozamia hopei*, growing to 18 meters, and *Dioon spinulosum*, 16 meters. These are exceptional for the family as a whole, however, for only a few members get taller than 3 meters, and many are less than 2 meters. *Zamia pygmaea*, the

smallest of cycads, has a stem at most 25 centimeters long and only 2 to 3 centimeters in diameter. Though the number of leaves in a crown seldom exceeds 25, at least one species (*Macrozamia moorei*) may have as many as 100. Cycad leaves average perhaps one meter long. The extremes are those of *Zamia pygmaea*, only 5 to 6 centimeters long, and those of some species of *Encephalartos*, reported to reach a length of 5 or 6 meters.

Cycad plants are either male or female. The seed- or pollen-bearing structures (sporophylls) are usually aggregated into cones (Fig. 3). In *Cycas*, however, the leaflike female sporophylls are loosely arranged in crowns among the leaves (Fig. 4). The largest known cones are produced by some of the cycads. Female cones of some species of *Encephalartos* have been recorded to weigh as much as 90 pounds. Those of *Macrozamia denisoni* are about 2 feet in length. In contrast, those of *Zamia pygmaea* are about 5 centimeters long and weigh less than an ounce.

Cycad seeds have a coat differentiated into an outer fleshy layer, usually some shade of red with more or less of an orange cast, and an inner stony layer. The bulk of the seeds, however, is a firm, starchy endosperm, containing the embryo. Seeds vary in length from 13 millimeters (*Zamia pygmaea*) to 7.5 centimeters (some *Cycas* species).

The best extant account of the cycads is given by Prof. Charles J. Chamberlain in his book *The living cycads* (58). A more recent, much briefer work on this family is *Ancient seed plants: the cycads* (30).

Information on the economic botany of the cycads is diffusely scattered throughout world literature. There have been several sketchy reviews of the subject, notably those by Barbour *et al.* (30), Jackson (131), and Schuster (234). The present paper is not presented as an exhaustive review of the literature on cycads as economic plants*, although I believe that at least a majority of pertinent material has been located. With the exception of certain minor observations on *Cycas* gum and the *Cycas* leaf industry, all the data presented herein are from the various works cited. Throughout the paper I have used scientific names as I found them in the literature. No other course seems possible until the deplorable condition of taxonomy and nomenclature in the Cycadaceae is corrected.

Cycads as Food Plants

Cycads are used mainly as a source of food starch—either from the seeds or from the stems—in many parts of the world. They would appear to be of particular importance as a source of sustenance during hard times or in areas where the food supply is naturally limited. It is probable that the seed kernels and stem pith of all cycads can be used as food after treatment to remove any toxic principle that may be present.

A brief discussion of the terms "arrowroot" and "sago" seems appropriate at this point. The use of the terms is frequently characterized by a certain lack of lucidity. These words are often both applied to much the same type of starch, e.g., starches from cycad stems and seeds are called both "sago" (*Cycas*) and "arrowroot" (*Zamia, Macrozamia*). Starches called "sago" by one author may be called "arrowroot" by another. While it is perhaps futile to expect rigidity of usage of common (and commercial) terms such as these, the looseness of their application is regrettable. When used in context that does not indicate the plants involved, the terms "arrowroot" and "sago" may be essentially meaningless.

"Arrowroot" seems to have been first applied to starch derived from the tuber-

* The genus *Zamia* is to be treated in a separate paper by Dr. W. C. Sturtevant.

FIG. 1. *Macrozamia reidlei,* a Western Australian species. The seeds of this plant are eaten by aborigines, and the stem has been used by white settlers as a source of starch.

ous rhizomes of *Maranta* species, especially *M. arundinacea*. For the sake of clarity, the term should probably be restricted to *Maranta* starch, yet many are the guises in which the term is seen. East India "arrowroot" is from the tuberous rhizomes of *Curcuma angustifolia;* Tulema "arrowroot" is from those of *Canna edulis;* Brazilian "arrowroot" has its source in the swollen roots of *Manihot esculenta;* potato starch appears as British "arrowroot"; the subterreanean stems of Florida *Zamia* yielded Florida "arrowroot".

"Sago" would appear to be restricted properly to starches obtained from the stems of certain palms (e.g., *Metroxylon, Caryota, Corypha*) and cycads (e.g., *Cycas, Zamia, Macrozamia*). Certainly the word should not be applied—as it has been—to starch derived from seeds or tubers.

In the present paper, starches derived from the stems—both aerial and subterranean—of cycads will be referred to either as "stem starch" or "sago". Starch from cycad seeds will be called neither "sago" nor "arrowroot" but simply "seed starch". Some of these cycad starches are described by Decrock (**78**) and Pereira (**207**) (*Cycas*), Planchon and Juillet (**212**) (*Cycas*), and Reichert (**216**) (*Cycas, Dioon, Zamia*).

BOWENIA

The tuberous, subterranean stem of *Bowenia spectabilis* is cooked and eaten by aborigines in Queensland (**20, 127, 159, 165, 226, 286**).

CYCAS

Leaves as Vegetable

When 30 to 40 cm. long, the young, not yet quite unfolded, succulent leaves of several *Cycas* species (*C. circinalis, C. pectinata, C. rumphii,* and *C. siamensis*) are cooked and eaten as a vegetable in the Malay Peninsula (**52, 220**), some parts of the Philippines (**50, 97**), Assam (**47, 138**), and parts of Indonesia (**44, 65, 115, 116, 175, 196, 197, 234, 261, 281, 282**). The tender leaves of *C. circinalis* are said to be eaten by Ceylon natives in curries (**198**). Kinch (**141**) mentions the use for food in Japan of the young leaves of *C. revoluta* but supplies no details. In view of the known toxicity—at least to cattle—of the leaves of Australian *Cycas*, it is not surprising to read in Ochse (**197**) that the eating of "much" of the young shoots of *C. rumphii* is said to cause rheumatism in man.

Seeds

Cycas circinalis, C. rumphii—The mature, ovate-globose seeds—often called "fruits" or "nuts"—of *C. circinalis, C. rumphii,* and certain related species are about the size of a walnut or somewhat larger (up to 7.5 cm. long, according to Schuster, **234**). They have, in common with seeds of all cycads, a testa differentiated into an outer fleshy layer and an inner stony layer. The bulk of the seed, however, is made up of a firm endosperm (the "kernel") that contains about 20–30% of starch (**8, 19, 135, 231**). These seeds are often utilized as food or made into flour or starch after various treatments to remove the poisonous constituents.

In several reports that *Cycas* seeds can be eaten (**46, 50, 65, 76, 99, 113, 120, 132, 139, 153, 245, 282**), the manner of preparation and use of the seeds is not related. Other reports supply at least some of the details. In the Andaman Islands *Cycas* seeds are eaten after "cooking" (**202**; see also **171**). Seeds may be roasted (**30**), as in the Aru and Key Islands (**234**) and New Caledonia (**145**). Seeds of the Fijian variety of *C. circinalis* are boiled, and the softened kernel is eaten (**79**). Of the use of *Cycas* in Fiji, Parham (**201**) says: "The fruit is used by natives in place of bread in hard times". Among the Vaeddas of Ceylon, *Cycas* seed kernels are cut into

Fig. 2. *Macrozamia spiralis*, New South Wales. The underground stem has had commercial significance as a source of starch, and the seeds were an important food for the aborigines.

slices, dried, and ground into a meal. A dough made from this meal is then baked into cakes (190, 230). Baker (25) describes the use of *Cycas* seeds by Singhalese natives as follows:

> The nut . . . is nearly white when divested of its outer husk; this is soaked for about twenty-four hours in water. A slight fermentation takes place, and the gas generated, splits the nut open at a closed joint like an acorn. The nuts, partially softened by this immersion, are dried in the sun, and subsequently pounded into flour in a wooden mortar. This flour is sifted, and the coarser parts being separated, are again pounded, until a beautiful snow-white farina is produced. This is made into a dough by a proper admixture with water, and being formed into small cakes, they are baked for about a quarter of an hour in a chatty. The fermentation, which has already taken place in the nut, has impregnated the flour with a leaven; this, without any further addition, expands the dough when in the oven, and the cake produced is very similar to a crumpet, both in appearance and flavour.

Crushed *Cycas* seed kernels may be soaked in frequent changes of water over several days before they are made into cakes (185). Such treated kernels may also be made into a porridge, as observed by Teijsmann (260) in Java, or served as an extender with rice, as at Prince's Island (68, 113). Cakes prepared from *Cycas* seed meal were an important staple food of the aboriginal inhabitants of Guam (229). The use of *Cycas* meal on this island has continued to the present day. Many Guamanians display a sort of reticence about admitting that they use this meal. They will confess to having used it during World War II when food was scarce, but imply that they would not think of such a thing now. Though generally not talked about, Cycas seed meal is nevertheless widely used now on the island (Fosberg, *in litt.*). In the Nicobar Islands (170) *Cycas* seeds are made into a paste that is eaten in the form of cakes.

In Pemba (292) sun-dried *Cycas* kernels are fermented in a tin with layers of banana leaves for about a week. They are next cleaned of mold, soaked a day in water to soften, and finally powdered and used as a porridge. The flesh, after longer storage with banana leaves, may be boiled and served as a vegetable. In the Moluccas a delicacy is prepared from *Cycas* seeds as follows: the kernels are cut into pieces, and then placed in a bag and steeped a few days in sea water. Then they are steamed and mixed with brown sugar and grated coconut (197).

The report that *Cycas circinalis* is a "common esculent" on the Comoro Islands (211) probably refers to the use of the seeds as an article of food as described by Stuhlman (259). The seeds are eaten after being put through a fermentation process. Interestingly enough, seeds of *Cycas rumphii* are included in Plate II, Some Inedible Fruits, in Macmillan's paper (158) on fruit cultivation in Ceylon.

Flour or starch prepared from *Cycas* seeds appears to be used mainly in India and Ceylon (3, 7, 26, 51, 86, 88, 120, 131, 132, 143, 145, 198, 231, 243, 272, 273, 285) but also sometimes elsewhere, including Indo-China (208, 214), the Philippines (97), the Moluccas (153), and New Caledonia (135). In the Marianas, starch from *Cycas* seeds is used for laundry purposes (280).

Of the use of *Cycas* seed flour in India, Buchanan (51) has this to say:

> The nuts are collected and, having been dried for a month in the sun, are beaten in a mortar, and the kernels formed into a flour, which the natives eat, and call Indum Podi. It is reckoned superior to the flour prepared from the stem of the Erimpanna (*Caryota*) but it is only used by the poor, who, between the 14th of July and the 13th of September are in danger of perishing. It is prepared during the former month, and cannot be preserved longer than the end of the latter.

For the preparation of starch in some localities in India, *Cycas* seeds are picked when ripe and then dried until the fleshy layer of the testa shrivels and cracks. In other localities full-sized but unripe seeds

are split and then dried until the kernel shrinks and separates from the testa. In either case further steps in the preparation of starch from *Cycas* seed kernels are almost identical with those used to prepare sago from *Cycas* stems (7).

A *Cycas* plant is said to produce annually about 550 seeds (135). These traction of starch from the seeds is said to be more economical (7, 231).

Opinions of the quality of *Cycas* seed starch vary considerably. Some think it to be of "bad quality" (153) or "inferior" (243). Safford (229) says the starch is not very white and has a disagreeable odor. On the other hand, Pe-

FIG. 3. (Left) Female cone of *Macrozamia moorei*, near Springsure, Queensland. The kernels of the seeds are poisonous. (Right) Male cone of *Macrozamia spiralis*, New South Wales.

seeds yield approximately the same quantity of starch—about 5 pounds—as can be obtained from a *Cycas* stem 4 feet long. There would appear to be no good reason—other than custom—for the destruction of entire *Cycas* plants to obtain starch from their stems—an unfortunate way to exploit a food plant of such slow growth, especially since the extraction of starch from the seeds is said to be more economical (7, 231).

telot (208) calls it of better quality than rice starch. Doubtless the quality of the finished product depends in large measure on the methods and care used in its manufacture.

Cycas media.—Members of Captain Cook's party were the first Europeans to observe the Australian aboriginal's use of the seeds of *Cycas media* for food (29,

53, 68, 165). In 1770 the explorers, noting "hulls" of the seeds scattered plentifully around the places where the natives had made fires, rightly assumed the seeds to be an article of food. Later writers either merely mention such use (31, 49, 93, 127, 234) or describe the methods by which the seeds are made fit to eat, that is, how the poisonous principle is removed or rendered inert (21, 150, 156, 159, 200, 226, 263, 264, 266, 267, 268). Though the various descriptions vary somewhat in certain details, that of Thozet (268) may be regarded as typical.

> The nuts are deprived of their outer succulent cover (sarcocarp), and are then broken; and the kernels, having been roughly pounded, are dried three or four hours by the sun, then brought in a dilly-bag to the water stream or pond, where they remain in running water four or five days, and in stagnant water three or four days. By a touch of the fingers the proper degree of softness produced by maceration is ascertained. They are afterwards placed between the two stones mentioned, reduced to a fine paste, and then baked under the ashes in the same way that our bush people bake their damper.

The following statements from Thomson (266) are of interest:

> Vast quantities of [*C. media* seeds] are gathered in the course of the year. It has the merit that, unlike most other foods of the aborigines which must be eaten immediately after preparation, it can be kept for some days or weeks. The fact that it is abundant gives [this food] a special value in native economy, for it enables the women to maintain an adequate food supply on ceremonial occasions when hundreds of people are gathered in one camp for weeks or months at a time, who could not otherwise be supported for such periods on local resources.

According to Lumholtz (156), the seeds of *C. media* constitute "from October to December, the principal food of the blacks" of Queensland. More recently, Thomson (264) called these seeds "the most important staple food" in Arnhem Land during most of the year (see also 265, 266) (Fig. 5). In contrast, the Larrakeeyah tribe of the Northern Territory eats the seeds only in the ceremonies of "making" young men (165). Other tribes use the seeds in connection with funeral ceremonies (36). *Cycas media* seeds are evidently eaten also by the aborigines of Melville Island off the northwest coast of Northern Territory (258).

Of the use of *C. media* seeds as food on ritual occasions, Thomson (266) writes:

> [It] is also the principal food eaten in Arnhem Land on ritual occasions. After it has been received by the old men it is then dedicated ceremonially to the ränga, the sacred totemic object, by the Dälkärrämirri, who recites aloud over it the "big" or sacred names of the totem. It now becomes sacramental food and may not be eaten or even handled by the profane, that is, by any but men fully initiated to the particular totem to which it has been dedicated.

Cycas revoluta.—Both the fleshy testa—said to have a sweet mucilaginous taste (205)—and the starchy kernel of the seed of *C. revoluta* ("sotetsu") are edible (3, 37, 47, 113, 121, 139, 141, 153, 184, 205, 234, 246, 254, 270, 294), the latter after proper treatment to remove the poisonous principle (189, 193, 231). Smith (246) found in the roasted kernels "the flavour of chestnuts, with less sweetness and a more watery consistence". Hooker (121) described the taste as "mealy, dry, sweetish, but insipid". Seed kernels were proclaimed a nourishing food by Peckolt (205) and so they probably are because they contain 12–14% crude protein and 66–70% starch (52, 193, 205, 231, 294). Nishida (191) studied the changes in chemical composition of the seed during its various stages of ripening. In the Satsuma province of Japan, the kernels are said to be pulverized and mixed with wheat and millet flour to form an edible paste (184). Seeds of *C. revoluta* have been considered and studied as raw material for the brewing industry (189).

C. revoluta, a "common" (248) or "ubiquitous" (254) plant in at least some of the Ryukyus, is an important source

of food there. Following a list and discussion of menus in typical homes on Amami Oshima, an island in the northern Ryukyus, Haring (108) has this to say about the use of cycad seeds as food:

> The foregoing menus fail to indicate the large reliance upon ground cycad (sotetsu) nuts on Amami Oshima. Amamians themselves refer to their island as "The Cycad Hell"—a nickname also applied derisively by outsiders. The cycad is a less useful relative of the sago palm. It grows very well in Amami's poorer soils, on steep hillsides—anywhere, in fact, for a variety of factors conspire to make Amami ideal for cycads. Moreover, drouths, floods, and typhoons seem to have little effect on the ubiquitous cycads. [Their] value to Amamians . . . is as a backlog when other crops fail through drouth or storm damage—occurrences all too frequent. So the large orange nuts that grow in a cluster atop the stems of cycads are harvested, shelled, dried, and ground to a sort of meal as a reserve against emergencies. Cycad meal is prepared variously, mixed with other foods to stretch them out, and made into *sake* —and universally disliked. In addition, as noted previously, it is slightly poisonous and every now and then a batch of especial potency kills those who eat or drink the product. In famine or near-famine, however, any food counts and aversions are discounted in favor of survival. In slavery days cycads had to enter more largely into the diet than now, since nearly all land was used to grow sugar for export.
>
> In connection with cycads, another menace looms large. The poisonous *habu* vipers often nest atop cycads and lay their eggs among the nuts. When a peasant reaches up to gather the nuts, the snake strikes, and one more death swells the total. This adds one more reason why the cycad is disliked even though it provides emergency food and liquor. It is apparent that the good housewife who listed her menus said nothing about dishes containing cycad; she serves them only *in extremis*, although she probably keeps the meal on hand.

Amamians do not like to talk about using *C. revoluta* as food. The subject is disagreeable when they are striving to make a good impression on a foreigner. They tell gladly about the export of cycas leaves (see section on cycas leaf industry). This yields cash, and the people are not ashamed of it. No one admits to having cycad seeds in his possession. Nevertheless, one can see everywhere the bright orange seeds spread out to dry (Fig. 6), and baskets full of the seeds are seen commonly in entryways (Fig. 7). The implication is always, "Of course the very poor eat cycad seeds, but I do not know about such things". As for the *sake* made from cycad seeds, it is in general use on Amami Oshima. The taste has been described as bitter like strychnine and quite long-lasting. Those who drink the *sake* sometimes become violently ill or even die; for this reason the brew is called *doku sake*—poison *sake* (Haring, *in litt.*, also 109).

In at least some of the Ryukyu group, cycad seeds are prepared as follows. They are collected, dried somewhat, and split. The halves of the kernel are removed from the testa, dried more, and then grated. Washing removes the starch from the pulp, and the starch is further washed in constantly changing water for 24 hours. There appears to be a certain correlation between the utilization of sotetsu seed starch and the density of population in relation to agricultural resources. For example, it is more extensively used on the poor islands Miyako and Kurashima than on Ishigaki, an island that has fewer people in relation to resources (Fosberg, *in litt.*).

Stem Starch

Cycas circinalis, C. rumphii.—The starchy pith and cortex of *C. circinalis*, *C. rumphii*, and certain related species may be eaten after cooking (135). Their importance, however, lies in the fact that a starch—called cycad sago—is extracted from them for use as food (28, 56, 60, 139). This product is made and utilized in several areas in southern and southeastern Asia and Oceania, including New Caledonia (135, 178), Timor (262), Indo-China (52, 75, 78, 135), Malaya (220), India, Burma, and Ceylon (7, 47, 99, 105, 136, 143, 145), Fiji (131, 239,

240), and the Solomons (203). *Cycas sago* is said also to be used in Madagascar (32, 33, 215, 279).

To be suitable for the extraction of sago, a *Cycas* plant should not have fruited, as fruiting depletes the store of starch in the stem. Most *Cycas* plants are capable of yielding large amounts of starch at about 7 years of age. The best time for the extraction of starch is just before a flush of new leaves (7).

Of the method of extracting and processing the starch, Anonymous (7) writes:

> On the discovery of a well-grown promising individual, it is felled flush with the ground and divested of its fronds as well as of the dry outer layers of its annularly furrowed stem. It is then carried to the home of the operator where he proceeds to cut away all the remaining part of the stem except the innermost cylindrical axis. This delicate core is now carefully sliced into thin, oval or circular discs which are spread upon mats and dried in the sun. When quite crisp, they are pounded into flour which is thereafter sifted and mixed in water. The resultant mess is then poured into a pot and allowed to stand until the starchy substance is deposited at the bottom and sides of the vessel. The clear liquid above the deposit is now drained off and the precipitate itself, while yet fresh, rolled about between boards until it resolves itself into the spherical pellets that are known as sago. These pellets, on drying and partial steaming, are passed through sieves that are graduated variously for the several grades, such as "bullet sago", "pearl-sago" and the like. The majority of Indian manufacturers, however, are content with the production of the amorphous meal which, after desiccation, is stored up for use.

Cycas revoluta.—Sago can be extracted from the stem of *Cycas revoluta* (3, 16, 27, 28, 47, 75, 90, 118, 184, 271, 282, 296). An early report, made in 1696, emphasizes that sotetsu sago is important as a food in times of famine (66). The use of sago from *C. revoluta* has continued to the present day. The inhabitants of the Ryukyu Islands rely upon sotetsu sago in times of food shortage such as may occur after typhoons (189, 282). During the food crisis of World War II, sotetsu sago was much used in this area (16). Thunberg (113, 121, 153, 270) made some seemingly extravagant statements about *C. revoluta* in 18th Century Japan: that this plant was highly esteemed as a food source, especially by people of rank; that the export of the plant was forbidden; and that a small portion of the pith could sustain life for a very long time.

On Amami Oshima, sago is prepared from sotetsu as follows (16). First the trunk is "debarked" and cut into small pieces. The chopped fragments are dried in the sun and then fermented. The stem material is placed in a bamboo basket and leached many times with water. The water is caught in a wooden tub in which the starch is allowed to settle (Fig. 8).

Upon analysis, air-dry matter of the stem of *C. revoluta* was found to contain 44.5% starch and 9.15% crude protein (296). In composition of the stem, male plants differ from the female plants of *C. revoluta* (189). At the same time, composition of both varies from season to season. Starch content is distinctly higher in the male, varying from 27% (calculated to dry substance) in October to 61% in June and averaging over the year 50%. In contrast, the female stem averages only 26%. In the female plant, starch content of the stem is greatly affected by seed production, apparently more than a year being required to synthesize the amount of starch consumed therein. In considering the use of sotetsu as a source of starch for industrial purposes (particularly brewing), it has been suggested that male trees only be cut down and that females be left as a source of starch-rich seeds.

Root Nodules

Peckolt (205) studied the root nodules of *C. revoluta* and found them to contain about 18% starch calculated to moist substance. The flesh was described as white, potato-like, and of a peculiar,

FIG. 4. Seed-bearing megasporophylls of *Cycas media*, near Rockhampton, Queensland. The seeds, after treatment to remove the poisonous principle, are a principal food of Queensland and Northern Territory aborigines.

sweetish, mild, not unpleasant flavor. When cooked, the nodules had an insipid, slightly sweet taste.

DIOON

The kernels of the large seeds of *Dioon edule* and *D. spinulosum* contain much starch and are said to be roasted or boiled and eaten (252) or used as a source of meal or starch (27, 58, 90, 94, 131, 135, 154, 155, 216). Plants of the recently described Honduran species of *Dioon, D. mejiae*, are said to be protected by the government because of their value to the Indians who boil and grind the seeds and make therefrom a sort of tortilla (253). The fleshy testa of *Dioon* seeds can be used as food (119), and sago can be obtained from the stem (139). *Dioon* seeds are a favorite food of bears, peccaries, and domestic swine (252).

ENCEPHALARTOS

The first description of the use of the pith of *Encephalartos* to make what has come to be known as "Kaffir bread" was given by Thunberg (269). Later (271; see also 122, 243) he wrote the following, somewhat more brief account:

> It is out of the pith (medulla) of this tree, that the Hottentots contrive to prepare their bread. For this purpose, after scooping out the pith, they bury it in the earth, and leave it there for the space of two months to rot, after which they knead it, and make it into a cake, which, in their usual slovenly and filthy manner, they slightly bake in the embers.

Another account of this use of *Encephalartos* is that given by Sparrman (249) as follows:

> The pith or marrow (medulla) which abounds in the trunk of this little palm, is collected and tied up in dressed calf or sheep skins, and then

buried in the earth for the space of several weeks, till it becomes sufficiently mellow and tender to be kneaded up with water into a paste, of which they afterwards make small loaves or cakes, and bake them under the ashes.

The Dutch colonists of South Africa, in consequence of this practice of the aborigines, gave the names "Kafferbroodboom", "Hottentotbroodboom", or simply "broodboom" (bread tree) to several species of *Encephalartos*, names which are still in use.

Although manifestly second-hand reports of the manufacture of Kaffir bread have continued to appear to the present time (**27**, **30**, **90**, **91**, **129**, **174**, **179**, **215**, **245**), there seems to be little or no first-hand evidence that species of *Encephalartos*—plants of limited distribution and often hard of access—are today used as described over 150 years ago. The general cultivation of maize in South Africa would seem to eliminate the need to resort to such a food plant except, perhaps, in case of dire emergency.

Williams (**292**) writes as follows concerning the use of *Encephalartos hildebrandtii* as food:

> The spongy farinaceous centre of the trunk, gwede, is used in Zanzibar as food in times of shortage. It is prepared by chopping small pieces, then heaping for about a week, to allow fermentation to take place for the neutralization of certain toxic substances. They are then washed, preferably in hot water, and dried in the sun, after which they are pounded and used as porridge, or by putting the flour into boiling water and continuing the boiling for some time and then stirring into a thick paste known as "ugali".

In times of famine, as an emergency food, Thonga natives in the Mexixe district of Mozambique cut the stem of *Encephalartos transvenosus* into slices. These are buried until a certain degree of fermentation is attained. The slices are then sun-dried and crushed in a mortar to reduce the pulp to a flour. This flour is then eaten after boiling (Young, *in litt.*). Kaffirs in Mozambique were reported, a century ago, to make a flour from the stem of *E. ferox* (**42**). According to Schweinfurth (**235**), certain central African natives make a sort of beer out of the central portion of the stem of a species of *Encephalartos*. Robyns (**224**) suggests the use of the pith of *E. poggei* as an emergency food.

The seeds of various *Encephalartos* have been stated to be the source of Kaffir bread (e.g., **94**, **149**), in spite of the lucid accounts of Sparrman and Thunberg. The fleshy testa of at least some species is apparently edible (**137**), the seeds being called "wilde datel" (wild dates). As to be noted later, the poisonous principle of *Encephalartos* seeds seems to be present only in the kernel. Nevertheless, the kernels of the seeds of *E. hildebrandtii* are reported to serve—surely after preparation, as in the case of *Cycas* seeds—as a famine food near Mombassa (**117**, **215**).

Several kinds of wild animals are reported to eat the seeds of *Encephalartos*. Baboons and monkeys collect and carry the seeds to the tops of cliffs or trees, rejecting the kernel and eating only the fleshy testa (Young, *in litt.*). Indeed, Prof. Chamberlain (**59**) describes the difficulty he had in finding ripe seeds of *Encephalartos* in areas where baboons carry away the cones before the seeds are ripe. Baboons, which even pull up young seedlings to eat the remnants of the seed, are a possible threat to the survival of *Encephalartos* in some areas where the leopards that usually limit the baboon population are shot for their skins and to protect livestock (**181**). Miss Verdoorn (*in litt.*) tells of seeing signs that rodents eat the fleshy part of the seed: heaps of kernels can be found under rocks. *Encephalartos* seeds are said to be eaten by elephants also (**181**).

MACROZAMIA

Seeds

In south Western Australia the fleshy coat of *Macrozamia* seeds (*M. reidlei*,

FIG. 5. Aboriginal women and *Cycas media*, Arnhem Land, Northern Territory. Seeds of this cycad are a major source of food for the aborigines, and the annual harvest amounts to many tons.

M. dyeri), rather than the starchy kernel, is eaten by the aborigines (**18**, **85**, **89**, **102**, **103**, **165**). Typical of the descriptions of the preparation of the seeds for food is that given by Grey (**102**).

> In the natural state the pulp of this nut is poisonous, but the natives who are very fond of it, deprive it of its poisonous qualities by first soaking it in water for a few days, and then burying it in the sand, where they leave it until the pulp is nearly dry; it is then fit to eat. They generally roast it.

Edwards (**89**) remarks that it is not uncommon to find the seeds undergoing the soaking process "either in shallow brooks or suspended by a string attached to a stake on the sea beach." The fleshy coat of the seeds is said to form a chief article of food in the autumn (**85**). Europeans who have eaten the prepared seed coats differ in their appraisal of the flavor, some finding it disgusting, rancid, and like train oil (**85**), while others consider it quite as good as that of a chestnut (**103**).

The earliest mention of the use of *Macrozamia spiralis*—"burrawang"—for food by the aborigines of New South Wales was made by Governor Phillip in 1788 as follows: "There, the natives eat also the kernels of that fruit which resembles a pineapple" (**210**; see also **35**, **165**, **284**). According to Maiden (**163**), one of the most important sources of food for the New South Wales aborigines was the seeds of *Macrozamia* (see also **187**). Before the kernels could be eaten, they were made innocuous by a process of roasting, pounding, and soaking in water (**28**, **70**, **131**, **186**, **187**, **234**). "The blacks roast and pound the seeds of *Zamia spiralis*, and then place the mass for two or three weeks in water, to take out the bitter principle, after which it is eaten" (**18**).

The preparation of the seeds of *M. miquelii* for food by the aborigines of northern Queensland is described as follows (**267**, **268**; see also **21**, **274**):

> The seeds, orange-red when ripe, and separating freely, are baked for about half an hour under ashes; the outside covers and the stones are then broken, and the kernels, divided by a stroke of the kondola, are put in a dilly-bag and carried to a stream or pond, where they remain six or eight days before they are fit for eating.

A starch, called of excellent quality (**159**, **163**), can be manufactured from seeds of *M. spiralis*. The quantity of seeds produced by these plants is said to be prodigious (**165**). Samples of the starch have been shown at exhibitions in Europe and Australia (**39**, **40**, **165**, **187**). Moss (**187**) describes as follows his method of preparing starch from burrawang seeds (see also **186**):

> I had the shells broken from the nuts, then placed in tubs of pure water and pounded quite soft with a wooden rammer; then roughly strained to get all the debris of the nut away; then strained through fine cheesecloth, and the liquid alowed to stand for forty-eight hours in a long cask, plenty of fresh water being added in the interval. I had spill holes made in the cask within a few inches of the bottom, so that the water could be drawn off without disturbing the sediment in any way. After draining and re-adding pure water several times, until the oil disappeared, then the arrowroot formed a cake at the bottom. The water was then all drawn off, the cake of arrowroot cut out and dried in the sun, and then, when dry, reduced fine by rolling.

Moss further tells of a child who, as a baby, was reared on "nothing else" but starch from burrawang seeds. Maiden (**165**) mentions a family that used such starch daily and found it very nutritious. Old newspaper reports tell of the use of the seeds of *M. spiralis* by early settlers for the production of starch (**127**).

M. spiralis seed starch grains have been described by Norrie (**195**). They are generally of two distinct sizes, "large and small," with few intermediates. The smaller grains are chiefly round, rarely oval, and not provided with a hilum. The large grains are perfect ovoids and resemble small bird's-eggs. Fresh burrawang seeds contain about 30–40% of

starch (**11**, **67**, **152**, **209**, **274**). Calculated to dry substance, starch content is about 65–70% (**11**, **204**).

Stem Starch

At least two species of *Macrozamia*—*M. spiralis* of coastal areas of New South Wales and Queensland, and *M. reidlei* (*M. fraseri*) of south Western Australia—occur in sufficient abundance to be of commercial importance as a source of starch from their stems (**67**, **152**). The aborigines of these areas, to whom *Macrozamia* seeds were an important article of food, seem never to have utilized the abundant starch contained in the stems of the plants (**148**, **188**). At least in Western Australia, early settlers made use of this starch which they extracted by a process described as follows (**57**; see also **89**):

> The pith of the stem is dried either in the sun or by heating in an oven, shredded up and soaked in water for six hours. It is then shaken up and filtered, the milky fluid being allowed to settle. The sediment is washed several times, dried slowly, and finely powdered, and is ready for use.

M. reidlei (*M. fraseri*) (Fig. 1) can attain a weight of more than a ton. Yield of starch from the roughly trimmed stem ranges from 25 to 40% calculated on the moist plant. On the same basis, fibrous material represents about 20%. *M. reidlei* starch has been used for laundry purposes as well as for food. Unfortunately, it appears that the starch has not yet been produced sufficiently pure—it always contained a small amount of finely divided fibrous matter—to be an acceptable product on the market (**227**).

Probably more than any other Australian cycad, *M. spiralis* (Fig. 2) has been investigated and exploited commercially for the starch in its stem. Burrawang has been considered as a source of starch for conversion into power alcohol (**67**, **111**, **152**). These investigations furnished some interesting data on the starch in burrawang stems. Starch content in various stems was found to vary considerably indeed—from 0.44% to 13.12% (whole stem) calculated from the yield of alcohol (approximately equivalent to percent of starch calculated upon moist plant). Stems from one area (Murwillumbah) were found to be useless as a source of alcohol because of their low starch content, while those from Bateman's Bay had a much higher starch content and so were of considerably more value as an alcohol source. This variation in starch content—both from plant to plant and from site to site—explains at least partially the discrepancies found in the figures given by various writers for the percentage of starch in burrawang stems (e.g., about 13% in Cook, **67**, to 25–30% in Penfold, **206**). Such figures may also vary depending upon whether the outer or inner core of the stem or the whole stem is analyzed. A transfer of starchy material from the outer to the inner core apparently takes place at certain times of the year with the result that the inner core is the richer in starch at these periods.

The investigators of *M. spiralis* as a starch source for alcohol production concluded that the burrawang has possibilities only in times of serious emergency. The high fiber content of the stem—particularly the outer core—was found to be a hindrance to the extraction of starch. "Until some use can be found for the fibre, or until it can be proved advantageous to hydrolyze it completely, attention must be confined to the inner core as a source of alcohol". Further, the manufacturer's cost for the stems was found to exceed considerably the price he could afford to pay and still make his business profitable (**67**).

In a venture distinct from that concerned with the production of alcohol from *M. spiralis*, a company was formed in New South Wales in 1921 to manufacture starch from this species (**206**;

see also 17). Only the central portion of the stem was utilized. This was ground with water, and the liquid was run over silk sieves, through which the starch passed but the fibrous material did not. The starch was purified by further washing and settling. The raw material cost about £4 per ton, much less than the cost (£12–£15 per ton) of corn, the raw material for corn starch.

graded accounts for the strength of this starch. The fine grains penetrate into the body of the fabric while the coarser ones remain on the surface. The starch, then, gives strength just where it is needed in the fabric.

Residual starches in the New South Wales factory were used for conversion into commercial adhesive paste. Penfold (206) mentions that such pastes are used

FIG. 6. Women spreading *Cycas revoluta* seeds on beach to dry in the sun, Amami Oshima. Seed kernels are ground to a meal and used for food.

Reports received from various laundries where burrawang starch was tested indicated that this starch was found to be 50–70% stronger than corn and rice starches (206). The explanation given for this is as follows. Rice starch consists of very fine grains, while corn starch is much coarser. *M. spiralis* starch grains are of various sizes from very fine (similar to rice) to coarser particles approaching the size of those of corn. The fact that the grains of burrawang starch are

in surprising quantities by manufacturers—not less than 10 tons per day were manufactured and sold in 1934 in New South Wales.

The burrawang starch factory prospered for a while, but owing to certain technical difficulties which developed, it was forced to close. It has never reopened. Efforts are made from time to time to re-establish the factory, but without success. The cost of labor would be prohibitive in Australia at the present

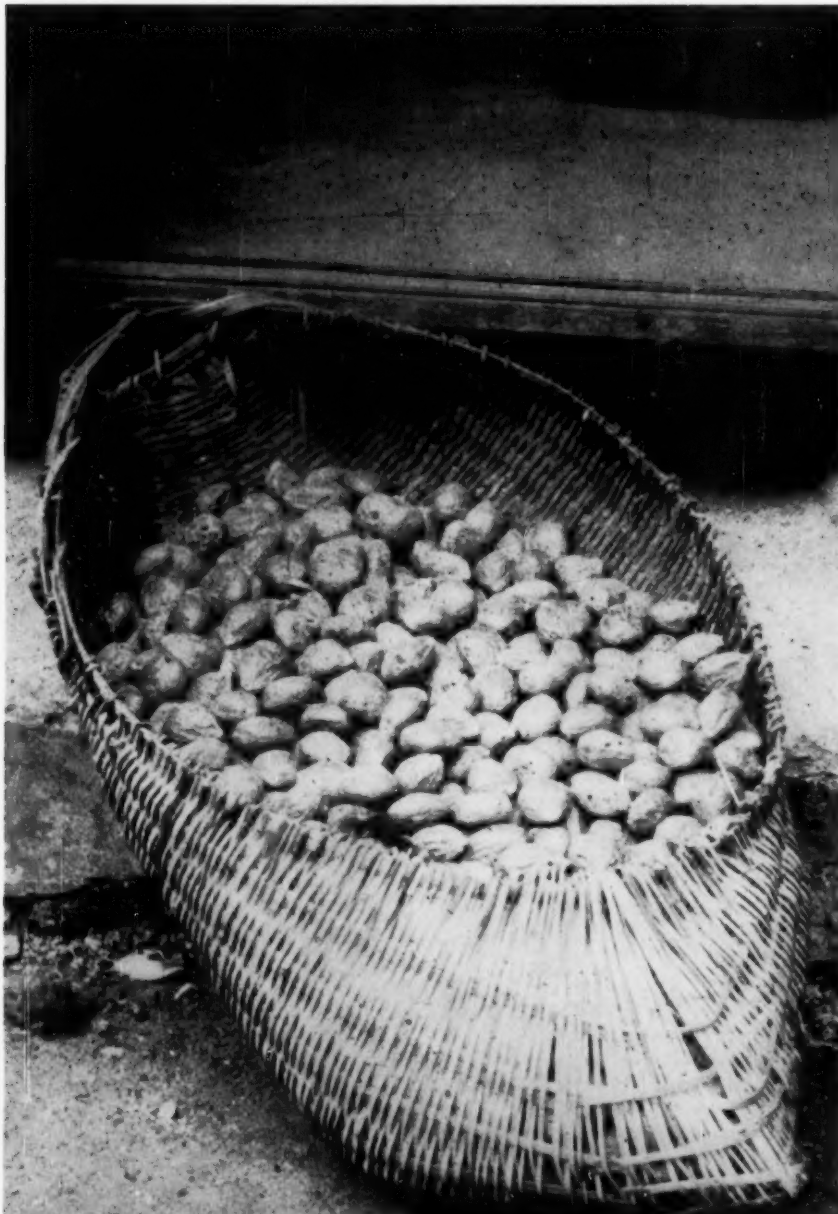

FIG. 7. Basket containing seeds of *Cycas revoluta,* Amami Oshima.

time. The main technical difficulty that developed was the occurrence of a slight brown stain on the starch particles after drying. This discoloration could not be removed economically (Penfold, *in litt.*).

Samples of burrawang starch have recently (1953) been submitted to the Division of Food Preservation and Transport, Commonwealth Scientific and Industrial Research Organization (Australia), for analysis with respect to suitability of the starch as a source of glucose (Gresford, *in litt.*). The yield of glucose from the starch was found to be 90.4%; the starch was free of the toxic macrozamin; and total nitrogen (calculated as protein) was 0.35%. According to Mr. M. C. Baggs of New South Wales, who has for years been endeavoring to get finance to exploit the burrawang, there is a prospective customer for 30 tons of starch per week to manufacture into glucose (Baggs, *in litt.*).

Utility of Macrozamia for Stock Food.—The starchy interior of the stem of several species of *Macrozamia* can be grated or ground, boiled in water, and used as food for poultry, pigs, and calves, the heat apparently inactivating the poisonous principle (57, 287). This food has been called "wholesome and nutritious" and has been highly recommended (89). On the other hand, it is interesting to note that, in a feeding experiment, a decline in egg production in poultry and an increase in time required for pigs to become ready for market were noted in animals fed upon *Macrozamia* (13).

STANGERIA

Baboons are said to be quite fond of the seeds, probably the fleshy testa only, of *Stangeria paradoxa* (58).

Cycads as Poisonous Plants

Seventy-five years ago, in the *Australasian Chemist and Druggist*, Baron von Mueller (188) made the following statement about the poisonous nature of cycads: "As pharmaceutic gentlemen will be aware, all Cycadeae are pervaded by a virulent poison-principle, which becomes inert or expelled by heat, and hence has eluded hitherto isolation in our chemical experiments." Information related to the poisonous properties of all genera of cycads except *Ceratozamia* and *Stangeria* has been found by the present writer. Heat, in at least one instance (238), did not reduce the toxicity of the poisonous principle of a cycad.

The ill effects attributed to eating portions of cycads seem to fall into two categories (63): (1) an acute, irritant effect, following the ingestion of seed kernels, manifested in man and other animals; and (2) a chronic, nervous affection, following the ingestion of cycad leaves, manifested especially in cattle.

BOWENIA

Bowenia spectabilis is regarded as definitely poisonous to stock that graze upon the leaves, the poison being cumulative and leading to weakness in the hindquarters (127, 286). The poisonous nature of this species has been proved by feeding tests (289). *Bowenia serrulata* has been reported to be very poisonous to cattle, causing lumbar paralysis (286). Macrozamin, the toxic crystalline substance first isolated from *Macrozamia spiralis,* has been found in *Bowenia serrulata* (what part not stated), while tests indicate that seeds of *B. spectabilis* probably contain this principle (222).

CYCAS

Seed kernels of *Cycas circinalis* were studied by Dongen (81) who isolated from them a toxic, amorphous glucoside that he named pakoein and considered to be the toxic principle of the seed. Pakoein is described as a pale yellow, amorphous powder, soluble in water, but insoluble in alcohol, benzene, chloroform, ether, methanol, acetone, and petroleum

FIG. 8. Extraction of starch from stem of *Cycas revoluta*, Amami Islands. (Upper left) Removal of outer layers of stem and chopping of stem into small pieces. (Upper right) Pieces of chopped stem drying in the sun. (Lower left) Leaching macerated stem material with water. The water is caught in a wooden tub. (Lower right) Bamboo basket containing macerated stem material. Starchy water can be seen in the tub below.

ether (15, 81, 87). With pakoein, in the seed of *Cycas circinalis*, is associated a cholosterin-like substance, phytosterin, said to be toxic (47, 52, 231). In a test of *C. circinalis* seeds for the presence of macrozamin, negative results were obtained by Riggs (223). Seeds of this species have been reported to contain prussic acid (73).

In Cambodia, seeds of *Cycas circinalis*, after crushing, are used for poisoning fish (208). In the Celebes the juice of *Cycas* seeds was given as a drink to children to kill them. This was done in instances in which the parents wished to continue, unburdened by a family, their nomadic way of life in the forests (115, 116).

The seeds of the Australian *Cycas media* (Fig. 5) have caused poisoning in Europeans who, unlike the aborigines, did not know how to treat the seeds to make them innocuous and fit for food. Members of Captain Cook's party ate some and learned that the seeds "operated both as an emetic and cathartic with great violence" (68; see also 29, 53, 165). Palmer (200) mentions that white men have suffered very much from accidentally or ignorantly eating *C. media* seeds. Seeds of this cycad have been shown to be toxic to cattle (127). *C. media* seeds fed to the Cook expedition hogs caused the death of two of the animals, and the rest were saved only "with difficulty" (29, 53, 68, 165). Macrozamin has been found in the seeds of this species (222). In central and northern Queensland *C. media* is a cause of "zamia staggers" in cattle that feed upon the leaves of the plant (92, 106, 127, 162, 167, 286). This cycad is reported to cause the disease also in horses and sheep (209).

According to Nishida (193), fresh seeds of *Cycas revoluta* contained 0.0164–0.220% of combined CH_2O (see also 132). After being crushed and dried in the sun, these seeds were found to contain 0.250–0.327% of total CH_2O, of which more than 96% was free. Yoshimura (*fide* 189) found 0.005% formaldehyde in *C. revoluta* stem and 0.15% in the kernel of the fresh seed. Yamafuji *et al.* (293) found 0.110 mg. of formaldehyde per 100 g. of fresh seed tissue, 0.074 mg. per 100 g. of stem tissue, and 0.021 mg. per 100 g. of leaf tissue of the "sago palm", this presumably being *Cycas revoluta*. The aldehyde content of the seed kernels is almost completely removed by soaking, washing, or boiling the slices (189, 193).

Nishida, Kobayashi, and Nagahama (194) isolated from seed kernels of *Cycas revoluta* a toxic glycoside, cycasin. The reactions of cycasin and its spectra were found to be similar to those of macrozamin. Riggs (223) considers cycasin to be identical with glucosyloxyazoxymethane isolated by him from seeds of *C. circinalis*.

DIOON

The buds and cones of *Dioon edule* (Fig. 9) are reputedly poisonous, causing emaciation and partial paralysis in cattle (176, 177, 252).

ENCEPHALARTOS

The seeds of *Encephalartos eugenemaraisii*, *E. longifolius*, and *E. villosus* have caused poisoning in humans (256, 257, 278). Reitz (219), in his book *Commando*, relates an incident wherein a number of men—including General Smuts—of a Boer commando became violently ill from eating the seeds of *E. altensteinii*. Two boys, of age twelve, are reported by Juritz (137) to have died from eating seeds of *E. cycadifolius* (*E. friderici-guilielmi*). An investigation of the seeds of this species was made, and an alkaloid was extracted from immature seed coats. However, this alkaloid, even in large doses, did not poison guinea pigs or white rats. The boys' deaths were then attributed to over-eating, and no explanation was forthcoming of the "ingestion of an irritant poison" mentioned in the post-

FIG. 9. *Dioon edule*, near Chavarrillo, Vera Cruz, Mexico. Tortillas are made from a meal obtained from the seeds of this species.

mortem report. Apparently the kernels of the seeds were not tested in this case for more recently it has been amply shown that the toxic principle in the seeds of at least several species of *Encephalartos* is apparently confined entirely to the kernels. This as-yet-unknown principle, a virulent liver-poison, has been demonstrated in the kernels of *E. cycadifolius*, *E. horridus*, *E. lehmannii*, *E. longifolius*, and *E. villosus* (256, 257, 276, 277). The liver-poison of *E. villosus* can be extracted with alcohol but is destroyed in boiling alcohol (Enslin, *in litt.*). Macrozamin has been discovered in *E. barkeri* (222) but in what part of the plant is not stated. On the other hand, in *E. villosus* no positive tests for macrozamin were found (Enslin, *in. litt.*).

MACROZAMIA

Seeds

A member of the genus *Macrozamia* was responsible for the first recorded case of plant poisoning of man in Australia (62). In 1697 Vlamingh and several of his men (near what is now Perth) learned, much to their discomfort, of the violently emetic effects of *Macrozamia* seeds (2, 57, 64, 114). Over a century later and also in Western Australia (at Lucky Bay, Archipelago of the Recherche), some of the members of the Flinders

expedition were "taken sick, and remained unwell all the day afterward" after eating *Macrozamia* seeds (**96**; see also **53**, **62**). The seeds of this same Western Australian species (probably *M. reidlei*, when eaten by several of Grey's men, caused "violent fits of vomiting, accompanied by vertigo, and other distressing symptoms" (**103**; see also **53**, **62**, **165**, **209**).

violent vomiting and purging have been followed, in the worst cases, by death, according to Lauterer (**148**). The seeds of a cycadaceous plant are said to have poisoned three boys at Springsure, Queensland (**199**). The species involved in the case is now known to have been *Macrozamia moorei* (Everist, *in litt.*).

FIG. 10. Poisoned specimen of *Macrozamia moorei*, a stock-poisoning cycad, near Springsure, Queensland. Arsenic is inserted into a notch made in the stem, and the plant soon dies.

Early records of New South Wales mention instances of poisoning from *Macrozamia* seeds (probably *M. spiralis*). These seeds are said to have "occasioned violent retchings" when eaten by some of the seamen of La Perouse in 1788 (**35**, **53**, **62**, **64**, **165**, **210**, **284**). Other records of *M. spiralis* poisoning in man are given by Bennett (**39**, **40**) and Milford (**186**). The usual symptoms of

In the Coonabaraban district of New South Wales in 1929 severe losses occurred among sheep that had eaten seeds of a species of *Macrozamia* first thought to be *M. spiralis* (**237**, **238**) but later identified as *M. heteromera* (**127**). Two mobs (**3000** each) of travelling sheep were involved. From the first, which merely touched the fringe of the burrawang country, **350** animals died; from the second, which crossed more of the burrawang country and spent more time there

than the first, a total of 1850 was lost. Losses continued for a considerable time —nearly two months—after the animals ate the seeds. Experimental feeding confirmed the fact that the seeds are toxic to sheep—from 4 to 8 ounces being the lethal dose—and also to cattle—2 pounds being the lethal dose for a yearling. The seed coat was shown to be non-toxic for sheep. Vomiting was produced in pigs after ingestion of 4 to 8 ounces of seed kernels. The poisonous principle of the kernels was not appreciably reduced by boiling them for up to an hour; however, drying the seeds to constant weight at 100° C. did reduce the toxicity considerably. The investigators concluded that the toxin is a "specific protoplasmic poison having a selective action on endothelial cells" (**238**; see also **127**, **290**).

Macrozamia spiralis seeds are known to be toxic to cattle, fowls, sheep, pigs, rabbits, and guinea pigs (**53**, **70**, **127**, **286**). Three days after the ingestion of fresh burrawang seeds rats died (**209**) but the experimenter ascribed their death to impaction. *M. moorei* seeds are said to cause horses to stagger somewhat in their front legs, to step high, and, eventually, to become nearly blind (**288**). Such symptoms, however, would appear to be those caused by ingestion of leaves rather than seeds. *M. reidlei* (*M. fraseri*) seeds are reported toxic to cattle, guinea pigs, and rabbits (**14**, **41**, **169**). Bailey (**20**) warned that the fruit of cycads is as dangerous to stock as the leaves—and probably even more so—and advised the destruction of the fruit before maturity and liberation of the seeds.

Leaves

Various species of Macrozamia, for more than ¾ of a century (**89**, **106**), have been recognized as the cause of a disease in cattle that browse upon the leaves. This disease, that causes serious economic loss in affected districts (**63**), has most frequently been called "rickets" or "wobbles"; however, "zamia staggers", a name suggested by Hall (**106**), is accepted and used here as being the most appropriate and descriptive.

Cycads are particularly attractive to cattle during dry seasons because the leaves often remain fresh and green at these times (**9**, **22**, **58**, **74**, **89**). A similar situation exists in recently burnt country where new *Macrozamia* leaves might be almost the only food available (**1**, **89**, **106**). Field evidence indicates that young shoots are more toxic than older leaves. Dry leaves have been found to be much less toxic than green ones (**107**).

Since the period 1890–1900, when the first detailed accounts of zamia staggers appeared (**5**, **74**, **89**, **126**), a considerable literature has been built up around the disease, a subject that has been called one of "immense importance" (**126**). Dr. T. L. Bancroft, who was commissioned by the Queensland government to investigate zamia staggers, gave this excellent description of the characteristic symptoms as manifested in cattle (**5**):

> The chief symptom of the disease is loss of proper control over the movements of the hind limbs. A rickety animal may run several yards without showing any peculiarity whatever, when suddenly it may drag its hind limbs, much like a dog sick from tick bite, or knuckle over upon its hind fetlocks, or may fall upon its haunches, immediately afterwards righting itself. Badly affected animals when excited a good deal, may fall quite helpless for a minute or more, after which they get up and walk away as if nothing was amiss with them, and are even able to jump fences.

If it continues to ingest zamia, the animal progressively grows weaker and, when it can no longer move about, dies from starvation (**58**, **74**, **89**, **148**, **167**, **255**). If an affected animal is removed from the source of zamia, however, the disease will not become any worse. The animal's handicap—lack of proper control of the hindquarters during locomotion—remains throughout the lifetime of

the beast because damage is apparently done to the nerves even before the development of symptoms (126). Such affected cattle may be fattened if placed upon good feed but, because they may fall down frequently during traveling, getting them to market is difficult, and there may be some slaughtering condemnation due to bruising (106). The milk and meat of zamia-affected animals are quite wholesome (55, 89, 106, 255).

Post-morten examinations of cattle affected with zamia staggers reveal no pronounced difficulties. There is often straining of the ligament of the hip joint and some straining and bruising of the ligament around the hock joint caused by the animal's lack of proper control over its movements (89, 106). Changes in the nervous system—the spinal cord and its membranes injected with blood, the meninges thickened, the arachnoid membrane covered with an exudate, the spinal cord considerably softened—were recorded by Crawley (74; see also 63). The clinical signs are suggestive of degeneration of the spinal cord (100). However, Hall (107) reported that sections of spinal cord and nerves stained with haematoxylin and eosin or prepared by the Marchi technique showed no abnormality. The same researcher, in an earlier paper (106), summarized succinctly this aspect of zamia staggers when he wrote that "methods . . . used so far have failed to reveal the damage that is the cause of the symptoms". Under some conditions the leaves of *M. paulo-guilielmi* can cause considerable liver damage with a severe terminal fibrosis of that organ (107).

The following *Macrozamia* species are reported to induce zamia staggers in stock: *M. douglasii* (106, 107), *M. miquelii* (20, 144, 167, 286), *M. moorei* (24, 58, 286, 288), *M. paulo-guilielmi* (106, 107), *M. platyrachis* (23, 127, 286), *M. reidlei* (incl. *M. dyeri*) (syn. *M. fraseri*) (1, 34, 41, 55, 57, 89, 98, 100, 114, 167, 172), and *M. spiralis* (63, 100, 106, 127, 167, 237, 238, 255, 286).

Macrozamia Eradication

Two courses may be followed in an effort to prevent stock from becoming affected with zamia staggers in areas where *Macrozamia* is present. The first of these involves fencing off badly affected areas, as has long been the practice in Queensland (106, 173). These areas often have to be opened to grazing in dry seasons, however, and it is at these times that serious loss of stock may occur.

The second course involves the eradication of *Macrozamia* plants, a difficult task in view of the great density of zamia palms in certain districts. Several methods are used to accomplish this destruction: (*1*) the plants may be grubbed out "by the roots" (133, 164, 173); it is of interest to note here that cattle can become affected with zamia staggers from eating the dried leaves and even the underground stems of such plants that may be left lying on the ground (164); (*2*) the plants may be "staked", that is, a sharp-pointed steel bar or crow bar with a chisel end may be used to split the stem, leading to rotting of the plant especially if done during the rainy season (1, 57, 89, 106); (*3*) zamia palms may be killed by the application of kerosene or arsenic to the "heart" or crown or, in the case of caulescent species such as *Macrozamia moorei* (Fig. 10), into a notch cut into the stem (1, 30, 34, 57, 58).

Poisonous Principle

Several investigators have attempted to isolate and identify the poisonous constituent of *Macrozamia*. The earliest of these was Norrie (186, 195), who believed potassium binoxalate to be the toxic substance contained in the seeds of *M. spiralis*. Lauterer (6, 148) ascribed the toxic properties of seeds of this

species to a resin soluble in ether. That *M. spiralis* contains no active poisonous principle that can be isolated or identified was concluded by Petrie (209). Oxalic acid, which has been found in *M. reidlei* seeds (1), has been suspected to be the toxic principle of *Macrozamia* (11), but has been exonerated by experiment (126). The presence of acid potassium oxalate in *M. reidlei* was held responsible for zamia staggers by Mann and Wallas (172; see also 1). The toxic principle of this species was found to be soluble in water and alcohol, to be neither a glucoside nor an alkaloid (169), not to be precipitated by lead acetate, and not to be extracted by immiscible solvents (14).

Cooper (70) isolated a crystalline substance, which she named macrozamin, from seed kernels of *M. spiralis*. Macrozamin was shown to be toxic to guinea pigs when administered orally but not when injected subcutaneously. Further research has shown the presence of macrozamin in *M. reidlei* (157) and *M. miquelii*, and its probable presence in *M. moorei*, *M. paulo-guilielmi*, *M. douglasii*, and *M. hopei* (222). Additional studies of macrozamin have been made by Jensen (134), Langley *et al.* (146), and Riggs (221).

MICROCYCAS

The roots of this plant are said to be used as a rat poison (57, 234).

Cycads as Gum Yielders

CYCAS

Of all the Cycadaceae, *Cycas* is the genus most frequently cited as a gum producer. As early as the beginning of the 19th Century (246) the exudation of gum from wounded megasporophylls of *Cycas revoluta* was noted in western literature. Certainly, however, *Cycas* gum was known in eastern countries long before its mention in literature.

The following species of *Cycas* have been reported to yield gum: *C. circinalis* (27, 28, 43, 44, 52, 69, 71, 86, 99, 125, 134, 145, 153, 155, 228, 229, 234, 273), *C. revoluta* (28, 153, 236, 228, 246), *C. rumphii* (115, 116, 125, 142, 143), *C. siamensis* (99, 143), and *C. thouarsii* (101). *Cycas* gum exudes through wounds in the megasporophylls (71, 115, 116, 246), stems (28, 69, 71, 72, 86, 99, 153, 273), and leaves (153, 236).

FIG. 11. Gum exuded from the broken tip of a megasporophyll of *Cycas circinalis*.

The writer has observed exudation of gum from megasporophylls of *C. circinalis* in the greenhouse of the University of Chicago. When the terminal portion of a sporophyll is broken off, exudation of gum from the now-exposed "gum-canals" of the basal portion commences immediately and is strongly reminiscent of the emergence of toothpaste from a tube. Flow of gum is confined almost entirely to the central area of the sporophyll where the "gum-canals" are in greatest concentration. Shortly after exudation begins, the gum from the various canals fuses into a mass, at first

mucilaginous and transparent but later hardening and becoming light brown (Fig. 11). *Cycas* gum can occur also as tears (**71**). Specimens of gum of *C. circinalis* in the Kew Museum are in "large dark brown lumps" (**125**).

When placed in water, *Cycas* gum begins to swell almost immediately. By the end of several days, it expands to many times its original size and becomes so colorless and transparent that it cannot be seen in water but must be felt for with a rod (see also **52, 71, 72, 101**). *Cycas* gum has been likened in its properties to that of *Sterculia tomentosa* (**71**).

Cycas gum has been used medicinally, particularly as an agent that is said to produce rapid suppuration when applied to malignant ulcers (**69, 86, 142, 143, 155, 225**). The gum has the repute of being a good antidote for snake and insect bites (**131, 234**). The use of *Cycas* gum as an adhesive has been reported (**115, 116**).

DIOON

The petiole of *Dioon edule* is said to yield a gum (**236**).

ENCEPHALARTOS

Some species of *Encephalartos* yield gum from the cones (**137**) or petioles (**236**). Gum is reported to exude from the stem of *E. lemarinelianus* (**291**). Specimens of gum of *E. hildebrandtii* in the Kew Museum consist of "clear yellow or pale brown pencils and tears" (**125**). *Encephalartos* gum is eaten by Kaffir children and by birds (**137**).

MACROZAMIA

Over a century ago in New South Wales, Backhouse (**18**) noted the exudation of an insipid, jelly-like gum, wholesome and not unpalatable, from *Macrozamia spiralis*. As early as 1855, *Macrozamia* gum, stated to be as "fine as amber," was exhibited in Europe (**244**). In addition to *Macrozamia spiralis*, the following species of this Australian genus are recorded as being gum yielders: *M. reidlei* (*M. fraseri*), *M. miquelii*, and *M. perowskiana* (*M. denisoni*) (**72, 160, 161**).

Macrozamia gum is exuded from cones, stems and bases of leaves (**45, 131, 147, 159, 160, 161**). Most reports mention only exudation through wounds but apparently spontaneous exudation occurs also (**18, 38, 39, 40**). In at least some instances, gumming follows attack on the plant by curculionid beetles (**160, 161**). Smith (**247**) ascribes a bacterial origin to *Macrozamia* gum.

Gums of the various species of *Macrozamia* are nearly identical in character (**166**) and have been described by various writers (**45, 125, 147, 148, 159, 160, 161, 204**). The gums occur in flattened pieces resembling "button lac", in scaly pieces that have been likened to unbleached and unpurified gelatin, and in tears. Placed in water, *Macrozamia* gum begins to swell almost immediately. The absorption of water goes on for several days, and by the end of this time the gum has swollen to from 50 to 100 times its original size. It then has the appearance of a colorless, quivering jelly. This behavior is much like that of cherry or acacia gums to which *Macrozamia* gums are apparently quite similar. The gum of *Macrozamia* was suspected once of being responsible for the poisonous effects of these plants but has been exonerated (**6, 148**).

Medicinal Uses of Cycads

In Assam, the pounded stem of *Cycas pectinata* is used as a hair-wash for diseased hair roots (**138**). In Cambodia, the mucilaginous terminal bud of *C. circinalis*, crushed in rice water or in water holding in suspension fine particles of clay, is used in the dressing of ulcerated wounds, of swollen glands, and of boils (**142, 182, 208**). The juice of young *Cycas* leaves is supposedly good for flatu-

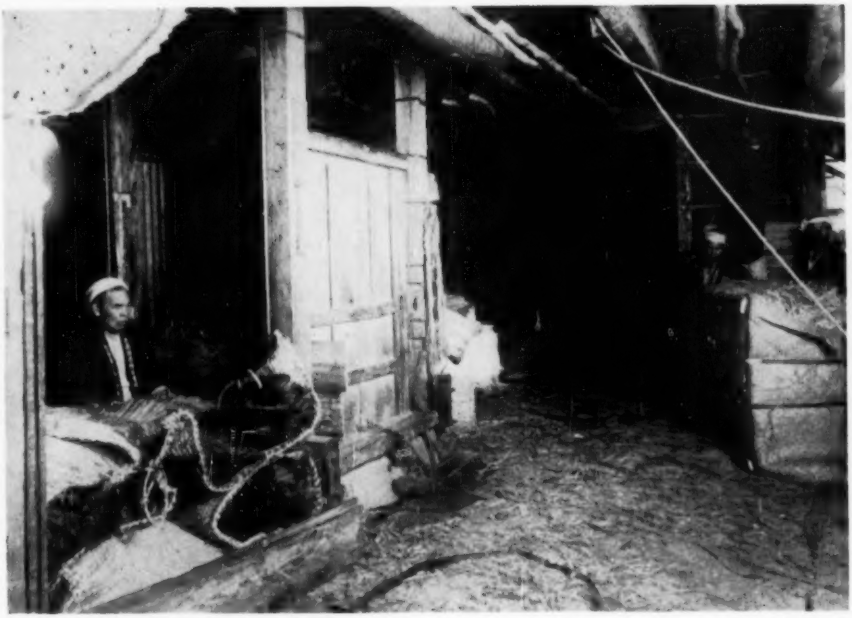

FIG. 12. (Upper) Packing dried leaves of *Cycas revoluta,* Okinawa. The leaves are exported to America and Europe where they are used mainly in the manufacture of wreaths and other floral decorations. (Lower) Bales of *Cycas revoluta* leaves being loaded onto scows, Okinawa.

lence and vomiting blood (52, 61, 231). The abundant pollen of *C. rumphii* is said to be strongly narcotic (220), as are the male cone scales of this species and *C. circinalis* that are commonly sold as an anodyne in bazaars in India (86, 225, 241, 285). The female cone, reduced to a poultice and applied to the loins, is reported to allay nephritic pains (86, 225). *Cycas* seeds, pounded to a paste in coconut oil, are used for sores, swellings, wounds, boils, and various skin complaints in parts of southern and southeastern Asia, Indonesia, and the Philippines (52, 61, 65, 104, 115, 116, 231). The young seeds of *Cycas*, decocted in water, are emetic and stomach-purifying, according to Hasskarl (112). *Cycas* seed flour, in Ceylon, is esteemed highly as a remedy in bowel complaints and haemorrhoids, for which purpose the flour is boiled and eaten (198).

A liquid decoction of the seeds of *Dioon edule* is said to be employed in Mexico for neuralgia (177, 252).

Cycads as Oil-Yielding Plants

Oils from two species of cycads have been studied. The fleshy layer of the seeds of *Macrozamia reidlei* contains a bright orange oil (28.2%) whose physical and chemical constants were found to resemble those of palm oil (14, 88, 169).

In his analysis of the seeds of *Cycas revoluta*, Peckolt (205) found the fleshy testa to contain 3.89% of an orange-yellow oil. Much more recently, analysis of sotetsu seeds revealed from 20.44–23.37% of oil, depending upon the method of extraction (88, 231, 275). Oil from the seeds of *Cycas revoluta* is said to have been used on Okinawa during the food crisis of World War II.

Cycads as Nitrogen Fixers

Many and possibly all cycads have, in addition to the primary tap root, numerous small secondary roots, some of which form the so-called root tubercles, root nodules, or coral-like roots (251). Reinke (218) studied these structures and showed the presence of an alga, *Anabaena*, in them. The presence of bacteria in the nodules was demonstrated by Schneider (233) who considered the alga, bacteria, and cycad to exist in a symbiotic relationship. Life (151) concluded that the nodules of cycads may have at least two functions: (1) that of aerating, and (2) that of assisting in nitrogen assimilation. In all bacterial cultures prepared by Bottomley (48) from the algal zone of cycad nodules, two nitrogen-fixing bacteria, *Pseudomomas radicicola* and *Azotobacter*, were associated.

That the roots of *Cycas revoluta*, with the assistance of *Anabaena*, are able to use the free nitrogen of the air was the conclusion reached by Yoshimura (295). More recently, Douin (82, 83) showed that cycad nodules with *Anabaena* contain more nitrogen than normal roots and that the alga is able to fix atmospheric nitrogen.

In addition to the papers cited above, several others have contributed to our knowledge of the root nodules of cycads (59, 84, 110, 123, 124, 250, 283). Photographs of nodules of *Cycas* and *Encephalartos* are reproduced in Kellerman (140).

While it is true that the cycads have no agricultural significance as nitrogen gatherers, their importance in the nitrogen cycle is at present unknown. Surely in areas where they are abundant they have played a role in the maintenance of the nitrogen supply.

Cycas Leaf Industry

Dried leaves of *Cycas revoluta* are exported in large quantities from the Ryukyu Islands for use as decorative material. This little-known industry is perhaps about 50 years old. A 1912 publication of the British Foreign Office refers to it as "recently developed". About 150 people are employed by the industry

FIG. 13. (Upper) Bales of *Cycas revoluta* leaves in warehouse of American Oak Preserving Company, North Judson, Indiana. The several processors in the United States preserve and hand-paint the leaves. (Lower) Open bale of *Cycas revoluta* leaves in warehouse of American Oak Preserving Company, North Judson, Indiana.

in Japan and the Ryukyus at the height of the season.

Cycas leaves are collected, starting at the end of July, in several islands of the Ryukyu group such as Amami-Oshima, Oki-erabu-shima, Yoron-jima, and Okinawa. There is no attempt to cultivate cycads for leaf harvest. The supply of wild plants is quite adequate although, at least in Okinawa, it is being reduced by the expansion of agriculture. After being cut from the plant and sorted into several size classes, cycas leaves are tied in bundles of five each and hung in a shady place to dry for about two months. They are then packed in bales that measure about $5 \times 4 \times 3$ feet (Fig. 12). The number of leaves per bale varies, depending upon the size of the leaves therein. Bales of 8- to 12-inch leaves contain about 26,000 leaves, while those of the 32- to 36-inch contain only 5000. About 1000 bales of cycas leaves are exported every year. They are sent from the Ryukyus to at least six brokers in Kobe, Yokohama, and Tokyo (Fig. 12). From there the leaves are shipped to overseas markets, chiefly the United States, Germany, and Switzerland.

An estimated 3,000,000 cycas leaves, with a gross value of about $30,000, are imported annually into the United States (Fig. 13). The price to the importers has increased about seven-fold since before World War II. The several processors here preserve and hand-paint the leaves. A typical preserving procedure involves boiling the leaves in water for a short time and then soaking them for several days in a preserving solution. A large percentage of prepared cycas leaves is used in the manufacture of wreaths and other floral decorations. Some leaves are used to make artificial palm trees for window displays.

Cycads as Horticultural Plants

Many species of cycads, representing most genera, are cultivated as ornamentals. They are fairly easily grown and are indeed handsome plants. In the tropics and subtropics the world over, cycads are used in out-of-door plantings. In cooler regions they are familiar in conservatories where they usually seem quite well adapted to their artificial surroundings.

Cycads as Fiber Plants

The fine, pulu-like surface fibers—called "palm wool" (89)—found at the base of the leaves of several species of *Macrozamia* and *Cycas* are used for stuffing pillows and mattresses (23, 65, 128, 159, 168). Surface fibers from the leaves of *Cycas revoluta* and *C. circinalis* have been made into cloth (184, 232). Before rubber was known in the Amami Islands, girls made balls by winding waste silk tightly on a core of "floss" from cycad leaves (109).

The leaves of various cycads (*Cycas*, *Encephalartos*) are plaited or woven into hats, baskets, mats, and fences (47, 95, 184, 213, 234, 242) and are utilized for thatch (80, 232) and brooms (254). Cordage and twine are said to have been made from *Cycas* "bark" ("écorce") (184) and from structural fibers of *Cycas* leaves (232). During the Exposition Universelle at Paris in 1867, "fibres du tronc" of *Cycas circinalis* were shown (4). The stem of *Macrozamia spiralis* has been found to be unsuitable as a source of paper-making fiber (12).

Miscellanea

At one time—but apparently not at present so far as I have been able to determine—the wood of *Cycas revoluta* was used in Japan to make small articles such as boxes, plates, and bottle stands. Rein's *The Industries of Japan* (217) mentions "the beautifully spotted but very light and porous wood" of sotetsu being utilized in the woodworking industry of the Hakone Mountains near Yokohama (see also 52, 234). Stems of

C. rumphii are, in Indonesia, used to build small houses (65). Maiden (159) says of the stem of *C. media*: "Of no use for timber purposes, but perhaps it might be useful to a limited extent for rustic work".

The dry, stony seed-coats of some of the cycads—e.g., *Dioon spinulosum* and *Cycas circinalis*—are sometimes used as playthings or whistles by children (58, 145). In parts of India, empty seeds of *Cycas circinalis* are used as snuff boxes (99), and, in Australia, empty seeds of *Macrozamia denisoni*, cut in two and provided with a hinge and clasp, are used as match boxes (58).

The fresh or dried leaves of various cycads serve as decorative material and are, in many areas, used in religious ceremonies, e.g., Palm Sunday processions as in Australia (131, 186), the Philippines (46, 50), and Goa (76), and in native rituals as in the New Hebrides (77) and the Solomons (130). Around Dresden, some years ago, entire hothouses were devoted to the growing of *Cycas revoluta* for its fronds that were used in funeral processions (131). Maumene (180) wrote on the production of *Cycas* leaves for decorative purposes.

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Literature Cited

1. Adams, A. B. The zamia palm and its destruction. Jour. Dept. Agr. West. Australia II. 2: 71–74. 1925.
2. Alexander, W. B. The history of zoology in Western Australia. I. Jour. Nat. Hist. and Sci. Soc. West. Australia 5: 49–64. 1915.
3. Anonymous. The sago palm (*Cycas revoluta* Willd.). Technologist 4: 384. 1864.

4. Anonymous. Exposition universelle de 1867. Catalogue des produits des colonies francaises précédé d'une notice statistique. 155 pp. Paris, 1867.
5. Anonymous. Rickets in cattle. The Queenslander, Oct. 29, p. 839. 1892.
6. Anonymous. The macrozamia plant. Chem. and Drug. Australasia **10:** 272. 1895.
7. Anonymous. Cycad sago. Trop. Agr. **26:** 385-387. 1906.
8. Anonymous. *Cycas circinalis*. Trinidad Bot. Dept., Bull. Misc. Infor. **59:** 85. 1908.
9. Anonymous. Burrawang or zamia. Agr. Gaz. N. S. Wales **23:** 1056. 1912.
10. Anonymous. Japan. Report for the year 1911 on the trade of Japan. Great Britain, Foreign Office, Dipl. and Cons. Reports, Annual Series, no. 4932. 1912.
11. Anonymous. Analysis of macrozamia or burrawang nuts. Agr. Gaz. N. S. Wales **28:** 625. 1917.
12. Anonymous. Paper-making in Australia. Bull. Imper. Inst. **17:** 415–421. 1919.
13. Anonymous. Utility of zamia palm for stock food. Agr. Gaz. N. S. Wales **33:** 169. 1922.
14. Anonymous. Poisonous principle of zamia fruit. The Analyst **65:** 292. 1940.
15. Anonymous. The Merck index of chemicals and drugs. 6th ed. Rahway, N. J., 1952.
16. Anonymous. Amami no shima-jima. (A survey account of the Amami Islands in the Ryukyu chain.) Tokyo, 1956.
17. Auden, H. A. Starch and starch products. London, 1922.
18. Backhouse, J. A narrative of a visit to the Australian colonies. London, 1843.
19. Bacon, R. F. Starch production in the Philippine Islands. Philipp. Jour. Sci. A. **3:** 93–96. 1908.
20. Bailey, F. M. Plants reputed poisonous to stock (order Cycadaceae). Queensland Agr. Jour. **2:** 131–133. 1898.
21. Bailey, F. M. The Queensland flora. V. Brisbane, 1902.
22. Bailey, F. M. The weeds and suspected poisonous plants of Queensland. Brisbane, 1906.
23. Bailey, F. M. Comprehensive catalogue of Queensland plants. Brisbane, 1909.
24. Bailey, J. F. Poisonous weeds in the Springsure district. Queensland Agr. Jour. **6:** 39–42. 1900.
25. Baker, S. W. Eight years in Ceylon. London, 1891.
26. Balfour, E. The cyclopaedia of India and of eastern and southern Asia. I. 3rd ed. London, 1885.
27. Balfour, J. H. Class book of botany. II. Edinburgh, 1854.
28. Balfour, J. H. A manual of botany. 5th ed. Edinbourgh, 1875.
29. Banks, J. Journal of the right honorable Sir Joseph Banks. London, 1896.
30. Barbour, E., *et al.* Ancient seed plants: the cycads. Mo. Bot. Gard. Bull. **43:** 65–80. 1955.
31. Barnett, L. The epic of man. I. Man inherits the earth. Life **39**(19): 73–99. Nov. 7, 1955.
32. Baron, R. The flora of Madagascar. Jour. Linn. Soc. Bot. **25:** 246–350. 1889.
33. Baron, R. Notes on the economic plants of Madagascar. Kew Bull. **45:** 203–215. 1890.
34. Baron-Hay, G. K. The kerosene method for eradicating the zamia palm. West. Australia Dept. Agr. Leaflet 103. 1923.
35. Barton, G. B. History of New South Wales from the records. I. Sydney, 1889.
36. Basedow, H. Anthropological notes on the western coastal tribes of the Northern Territory of South Australia. Trans. and Proc. and Rept. Roy. Soc. S. Australia **31:** 1–62. 1907.
37. Beckurts, H. Repertorium der Pharmacie. Die brasilianischen Nutzpflanzen. Apoth.-Zeit. **9**(73): 711. 1894.
38. Bennett, G. Gatherings of a naturalist in Australasia. London, 1860.
39. Bennett, G. On *Macrozamia spiralis*, or burrawang of New South Wales. N. S. Wales Med. Gaz. **2:** 1–4. 1871.
40. Bennett, G. A case of poisoning by the seeds of *Macrozamia spiralis*. Jour. of Bot., Brit. and For. **10:** 42–43. 1872.
41. Bennetts, H. W. Plants poisonous to stock in Western Australia. Jour. Roy. Soc. West. Australia **21:** xi–xxiii. 1935.
42. Bertoloni, G. Illustrazione di piante Mozambicesi. Mem. della Accad. delle Sci. del'Istit. Bologna **3:** 249–267. 1851.
43. Birdwood, G. C. M. Catalogue of the economic products of the presidency of Bombay; being a catalogue of the Government Central Museum. Division I. —Raw produce (vegetable). Bombay, 1862.
44. Bisschop Grevelink, A. H. Planten van Nederlanch-Indie brukbaar voor handel, nijverheid en geneeskunde. Amsterdam, 1883.
45. Blackett, C. R. The occurrence of bassora gum in the Cycadeae. Pharm. Jour. and Trans. III. **13:** 104–105. 1882.
46. Blanco, M. Flora de Filipinas. III. Manila, 1879.

47. Bor, N. L. Manual of Indian forest botany. Bombay, 1953.
48. Bottomley, W. B. Some effects of nitrogen-fixing bacteria on the growth of nonleguminous plants. Proc. Roy. Soc. London B. **81**: 287–289. 1909.
49. Brough Smyth, R. The aborigines of Victoria. I. Melbourne, 1878.
50. Brown, W. H. Wild food plants of the Philippines. *in* Brown, W. H., ed. Minor products of Philippine forests **2**: 239-377 (Philippine Dept. Agr. and Nat. Res., Bur. Forest. Bull. 22). 1921.
51. Buchanan, F. A journey from Madras through the countries of Mysore, Canara, and Malabar II. London, 1807.
52. Burkill, I. H. A dictionary of the economic products of the Malay Peninsula. I. London, 1933.
53. Burton, J. C. Plants, including fungi, poisonous or otherwise injurious to man in Australia. Agr. Gaz. Tasmania **22**: 361-367, 401–403. 1914.
54. Caldwell, O. W. *Microcycas calocoma*. Bot. Gaz. **44**: 118–141. 1907.
55. Cameron, S. S. Diseases of farm animals. Jour. Dept. Agr. Victoria **7**: 45–53, 100–110. 1909.
56. Capus, G., and Bois, D. Les produits coloniaux. Paris, 1912.
57. Carne, W. M., Gardner, C. A., and Bennetts, H. W. The poison plants of Western Australia. 2nd ed. West. Australia Dept. Agr. Bull. 96. 1926.
58. Chamberlain, C. J. The living cycads. Chicago, 1919.
59. Chaudhuri, H., and Akhtar, A. R. The coral-like roots of *Cycas revoluta, Cycas circinalis and Zamia floridana* and the alga inhabiting them. Jour. Indian Bot. Soc. **10**: 43–59. 1931.
60. Chevalier, A. Les Cycas d'Indochine. Rev. Bot. Appl. et d'Agr. Colon. **4**: 472–473. 1924.
61. Chopra, R. N., Nayar, S. L., and Chopra, I. C. Glossary of Indian medicinal plants. New Delhi, 1956.
62. Cleland, J. B. Plants, including fungi, poisonous or otherwise injurious to man in Australia. Australasian Med. Gaz. **35**: 541–544, 569–572. 1914.
63. Cleland, J. B. Plants poisonous to stock in Australia. N. S. Wales Govt. Bur. Microbiology, Rept. **3**: 187–217. 1914.
64. Cleland, J. B. Plants, including fungi, poisonous or otherwise injurious to man in Australia. Med. Jour. Australia **2**: 443–451. 1925.
65. Clercq, F. S. A. de. Nieuw plantkundig woordenboek voor Nederlansch Indie. 2nd ed. Amsterdam, 1927.
66. Cleyer, A. De arbore Japonensium tschooditsoo sive tschoot-itzu. Misc. Cur. Acad. Caes.-Leop. Nat. Cur. **3**: 208. 1696.
67. Cook, G. A. The possibilities of power alcohol and certain other fuels in Australia. Council Sci. and Indus. Res. (Australia) Bull. 33. 1927.
68. Cook, J. The three voyages of Captain James Cook round the world. II. London, 1821.
69. Cooke, M. C. Report on the gums, resins, oleo-resins, and resinous products in the India Museum or produced in India. London, 1874.
70. Cooper, J. M. Isolation of a toxic principle from the seeds of *Macrozamia spiralis*. Jour. and Proc. Roy. Soc. N. S. Wales **74**: 450–454. 1941.
71. Cordemoy, H. J. de. Gommes, résines d'origine exotique et végétaux qui les produisent particulièrement dans les Colonies Francaises. Paris, 1900.
72. Cordemoy, H. J. de. Les plantes à gommes et à resines. Paris, 1911.
73. Cranwell, L. M., and Green, J. E. Food is where you find it. Auckland, 1944.
74. Crawley, A. W. V. Zamia poisoning. Producers' Gaz. and Settlers' Record (West. Australia) **5**: 399–402. 1898.
75. Crevost, C., and Lemarié, C. Catalogue des produits de l'Indochine. I. Hanoi-Haiphong, 1917.
76. Dalgado, D. G. Flora de Goa e Savantvadi. Lisboa, 1898.
77. Deacon, A. B. Malekula. A vanishing people in the New Hebrides. London, 1934.
78. Decrock, E. Contribution à l'étude des fécules de l'Indo-Chine. Ann. Mus. Colon. Marseille II. **6**: 67–129. 1908.
79. Degener, O. Naturalist's south Pacific expedition: Fiji. Honolulu, 1949.
80. Dodge, C. R. A descriptive catalogue of useful fiber plants of the world. USDA Fiber Invest. Rept. 9. Washington, 1897.
81. Dongen, J. v. Bidji pakoe hadji (*Cycas circinalis* L.). Pharm. Weekblad **40**: 309–313. 1903.
82. Douin, R. Sur la fixation de l'azote libre par les Myxophycées endophytes des Cycadacées. Compt. Rend. Acad. Sci. Paris **236**: 956–958. 1953.
83. Douin, R. Nutrition azotée et nutrition carbonée des *Anabaena* endophytes des

Cycadacèes. Lyon Univ. Ann. 3 sér. Sci. Sect. C: Sci. Nat. **8**: 57–70. 1954.

84. Douin, R. Pigments des *Anabaena* endophytes des *Cycas*. Compt. Rend. Acad. Sci. Paris **239**: 76–78. 1954.
85. Drummond, H. Useful products of Western Australia. Technologist **2**: 25–28 1862.
86. Drury, H. The useful plants of India. 2nd ed. Madras, 1873.
87. Duyster, M. Giftige indische planten en plantenbestanddeelen. Bandoeng, 1927.
88. Ecky, E. W. Vegetable fats and oils. New York, 1954.
89. Edwards, H. H. Report of the government veterinary surgeon on the disease known as "rickets" or "wobbles". Jour. Bur. Agr. West. Australia **1**: 225–234. 1894.
90. Eichler, A. W. Cycadaceae. *in* Engler, A., and Prantl, K. Die natürlichen Pflanzenfamilien II. **1**: 6–26. 1889.
91. Engler, A. Die Pflanzenwelt Ost-Afrikas und der Nachbargebiete. B. Die Nutzpflanzen Ost-Afrikas. Berlin, 1895.
92. Ewart, A. J. The weeds, poison plants, and naturalized aliens of Victoria. Melbourne, 1909.
93. Eylmann, E. Die Eingeborenen der Kolonie Südaustralien. Berlin, 1908.
94. Figuier, L. The vegetable world. London, 1867.
95. Fischer, C. E. C. Vol. 3 *in* Gamble, J. S. Flora of the Presidency of Madras. London, 1928.
96. Flinders, M. A voyage to Terra Australis. I. London, 1814.
97. Foxworthy, F. W. Philippine gymnosperms. Philipp. Jour. Sci. C. **6**: 149–177. 1911.
98. Fraser, M. A. C. Notes on the natural history, etc., of Western Australia. Perth, 1903.
99. Gamble, J. S. A manual of Indian timbers. London, 1922.
100. Gardner, C. A., and Bennetts, H. W. The toxic plants of Western Australia. Perth, 1956.
101. Greenway, P. J. Gum, resinous and mucilaginous plants in East Africa. East Afric. Agr. Jour. (Suppl.) **6**: 241–250. 1941.
102. Grey, G. A vocabulary of the dialects of south Western Australia. 2nd ed. London, 1840.
103. Grey, G. Journals of two expeditions of discovery in north-west and western Australia. London, 1841.
104. Guerrero, L. M. Medicinal uses of Philippine plants. *In* Brown, W. H., ed. Minor products of Philippine forests **3**: 149–246 (Philippine Dept. Agr. and Nat. Res., Bur. Forest. Bull. 22). 1921.
105. Haines, H. H. The botany of Bihar and Orissa. IV. London, 1922.
106. Hall, W. T. K. Zamia staggers in cattle. Queensland Agr. Jour. **79**: 173–177. 1954.
107. Hall, W. T. K. A note on macrozamia and xanthorrhoea poisoning of cattle. Australian Vet. Jour. **32**: 173–174. 1956.
108. Haring, D. G. The island of Amami Oshima in the northern Ryukyus. Pacific Sci. Board, Nat. Res. Council, SIRI Rept. 2. Mimeo. 1952.
109. Haring, D. G. Folk music of the Amami Islands. (Explanatory booklet in Ethnic Folkways Library record album no. P448.) New York, 1954.
110. Hariot, P. Sur une algue, qui vit dans les racines des Cycadèes. Compt. Rend. Acad. Sci. Paris **115**: 325. 1892.
111. Harker, G. *Macrozamia spiralis* as a source of industrial alcohol. Sci. and Indus. (Australia) **1**: 470–475. 1919.
112. Hasskarl, J. K. Aanteekeningen over het nut, door de bewoners van Java aan eenige planten van dat eiland toegeschreven. Amsterdam, 1845.
113. Hedrick, U. P., ed. Sturtevant's notes on edible plants. New York Dept. Agr. Ann. Rept. 27, vol. 2(2). 1919.
114. Herbert, D. A. The poison plants of Western Australia. West. Australia Dept. Agr. Bull. 69. 1921.
115. Heyne, K. De nuttige planten van Nederlandsch Indie. I. 2nd ed. Batavia, 1927.
116. Heyne, K. De nuttige planten van Indonesie. I. 3rd ed. 's-Gravenhage/Bandung, 1950.
117. Hildebrandt, J. M. Von Mombassa nach Kitui. Zeitschr. Gesell. f. Erdkunde Berlin **14**: 241–278. 1879.
118. Höhnel, F. V. v. Die Stärke und die Mahlproducte. Vol. I *in* Benedikt, R., *et al.* Allgemeine Waarenkunde und Rohstofflehre. Kassel and Berlin, 1882.
119. Hooker, J. D. *Dion edule*. Curtis's Bot. Mag. **101**: t. 6184. 1875.
120. Hooker, W. J. *Cycas circinalis*. Curtis's Bot. Mag. **55**: t. 2826, 2827. 1828.
121. Hooker, W. J. *Cycas revoluta*. Curtis's Bot. Mag. **57**: t. 2963, 2964. 1830.
122. Hooker, W. J. *Encephalartos caffer*. Curtis's Bot. Mag. **82**: t. 4903. 1856.
123. Horejsi, J. Einiges über die symbiontische Alge in den Wurzeln von *Cycas revoluta*. Bull. Inter. Ceska Akad. Cisare Frantiska Josefa **15**: 35–44. 1910.
124. Horejsi, J. Symbioticka rasa sina v korenech u *Cycas revoluta*. Rozpravy Ceske

Akad. Cisare Frantiska Josefa II. **19**(9): 1–32. 1910.

125. Howes, F. N. Vegetable gums and resins. Waltham, Mass., 1949.
126. Hunt, J. S. Rickets. Ann. Rept. Dept. Agr. Queensland 1898–1899: 71–72. 1899.
127. Hurst, E. The poison plants of New South Wales. Sydney, 1942.
128. Hutchinson, J. Contributions towards a phylogenetic classification of flowering plants. III. Kew Bull. 1924(2): 49–66. 1924.
129. Hutchinson, J., and Rattray, G. Cycadaceae. *In* Hill, A. W., ed. Flora Capensis V, sect. 2 (Suppl.): 24–44. 1933.
130. Ivens, W. G. Melanesians of the southeast Solomon Islands. London, 1927.
131. Jackson, J. R. Cycads. Intell. Observer **5**: 246–252. 1864.
132. Jackson, J. R. Notes on some African vegetable products. Technologist **4**: 471–477. 1864.
133. Jensen, H. I. The zamia problem. Agr. Gaz. N. S. Wales **21**: 101. 1910.
134. Jensen, H. L. Microbiological properties of macrozamin. Australian Jour. Sci. **6**: 125. 1944.
135. Jumelle, H. Les cultures coloniales. Plantes alimentaire. Paris, 1901.
136. Jumelle, H. Les cultures coloniales. Plantes a fécule et céréales. Paris, 1912.
137. Juritz, C. F. South African p'ant poisons and their investigation. Rept. 12th Ann. Meet. So. Afr. Assoc. Adv. Sci. 109–145. 1915.
138. Kanjilal, U. N., *et al.* Flora of Assam. IV. Calcutta, 1940.
139. Karsten, H. Flora von Deutschland, Oesterreich und der Schweiz. I. 2nd ed. Gera-Untermhaus, 1895.
140. Kellerman, K. F. Nitrogen-gathering plants. USDA Yearbook 1910: 213–218. 1910.
141. Kinch, E. List of plants used for food or from which foods are obtained in Japan. Trans. Asiatic Soc. Japan **11**: 1–30. 1883.
142. Kirtikar, K. R., and Basu, B. D. Indian medicinal plants. IV. Allahabad, 1933.
143. Kurz, S. Forest flora of British Burma. II. Calcutta, 1877.
144. Lamb, S. Plants injurious to stock—the zamia. Agr. Gaz. N. S. Wales **6**: 505. 1895.
145. Lanessan, J. L. de. Les plantes utiles des Colonies Francaises. Paris, 1886.
146. Langley, B. W., Lythgoe, B., and Riggs, N. V. Macrozamin. II. Jour. Chem. Soc. 1951: 2309–2316. 1951.
147. Lauterer, J. Gums and resins exuded by Queensland plants chemically and technologically described. Queensland Dept. Agr., Bot. Bull. **13**: 35–80. 1896.
148. Lauterer, J. New investigations on rickets and macrozamia. Proc. Roy. Soc. Queensland **14**: 5–13. 1899.
149. Lawrence, G. H. M. Taxonomy of vascular plants. New York, 1951.
150. Leichhardt, L. Tagebuch einer Landreise in Australien von Moreton-Bay nach Port Essington. Halle, 1851.
151. Life, A. C. The tuber-like rootlets of *Cycas revoluta*. Bot. Gaz. **31**: 265–271. 1901.
152. Lightfoot, G. Power-alcohol: proposals for its production and utilization in Australia. Australia Advisory Coun. of Sci. and Indus. Bull. **6**. 1913.
153. Lindley, J. Flora medica. London, 1838.
154. Lindley, J. *Dion edule*. Bot. Reg. **29**: misc. 59–60. 1843.
155. Lindley, J. Medical and oeconomical botany. London, 1856.
156. Lumholtz, C. Among cannibals. London, 1889.
157. Lythgoe, B., and Riggs, N. V. Macrozamin. I. Jour. Chem. Soc. 1949: 2716–2718. 1949.
158. Macmillan, H. F. Fruit cultivation in Ceylon. Trop. Agr. **25**(3): 486–494. 1905.
159. Maiden, J. H. The useful native plants of Australia. Sydney, 1889.
160. Maiden, J. H. *Macrozamia (Encephalartos)* gum. Chem. and Drug. Australasia **5**: 20, 44–45. 1890.
161. Maiden, J. H. *Macrozamia (Encephalartos)* gum. Pharm. Jour. and Trans. III. **21**: 7–8. 1890.
162. Maiden, J. H. Plants reputed to be poisonous to stock in Australia. Agr. Gaz. N. S. Wales **8**(1): 1–22. 1897.
163. Maiden, J. H. Some plant foods of the aborigines. N. S. Wales Dept. Agr. Misc. Publ. 217. 1898.
164. Maiden, J. H. Effects on cattle of eating macrozamia roots. Agr. Gaz. N. S. Wales **10**: 1259. 1899.
165. Maiden, J. H. Native food-plants. N. S. Wales Dept. Agr. Misc. Publ. 282. 1899.
166. Maiden, J. H. The gums, resins and other vegetable exudations of Australia. Jour. and Proc. Roy. Soc. N. S. Wales **35**: 161-212. 1901.
167. Maiden, J. H. Plants reputed to be poisonous to stock in Australia. N. S. Wales Dept. Agr. Misc. Publ. 477. 1901.
168. Maiden, J. H. Some Australian vegetable fibres. N. S. Wales Dept. Agr. Misc. Publ. 550. 1902.

169. Malloch, F. J. Chemical examination of the seeds of *Macrozamia reidlei* (zamia palm). Ann. Rept. Chem. Branch, Mines Dept., West. Australia **1939**: **13–14**. **1940**.

170. Man, E. H. The Nicobar Islands and their people. Guildford, England, n.d.

171. Man, E. H. On the aboriginal inhabitants of the Andaman Islands. London, 1883.

172. Mann, E. A., and Wallas, T. I. Investigation of the disease in cattle known as "rickets" or "wobbles", and examination of the poisonous principle of the zamia palm (*Macrozamia fraseri*). Jour. and Proc. Roy. Soc. N. S. Wales **40**: xxi. **1907**.

173. Marks, G. Zamia country in Tabulam district. Agr. Gaz. N. S. Wales **23**: **1056–1058**. 1912.

174. Marloth, R. The flora of South Africa. I. Capetown, 1913.

175. Marsden, W. The history of Sumatra. London, 1811.

176. Martinez, M. Las plantas mas utiles que existen en la Republica Mexicana. Mexico, 1928.

177. Martinez, M. Las plantas medicinales de Mexico. Mexico, 1933.

178. Massal, F., and Barrau, J. Food plants of the South Sea islands. South Pacific Comm. Tech. Paper 94. 1956.

179. Masters, M. T. *Encephalartos*. *In* Lindley, J., and Moore, T., ed. The treasury of botany. London, **1866**.

180. Maumene, A. Production des frondes de *Cycas* pour l'ornementation. Le Jardin **11**: **74–76**. **1897**.

181. Melville, R. *Encephalartos* in central Africa. Kew Bull. **1957**: **237–257**. **1957**.

182. Menaut, B. Matière médicale cambodigienne. Bull. Econ. de l'Indochine, N. S., no. **200**: **197–276**. **1929**.

183. Mène, E. Des productions végétales du Japon a l'Exposition Universelle de 1878. Bull. Soc. d'Acclim. (Paris) III. **7**: **349–386**. **1880**.

184. Mène, E. Des productions végétales du Japon. Bull. Soc. d'Acclim. (Paris) III. **8**: **346–379**. **1881**.

185. Merrill, E. D. Emergency food plants and poisonous plants of the islands of the Pacific. US War Dept. Tech. Manual TM 10-420. **1943**.

186. Milford, F. The *Macrozamia spiralis*. Jour. and Proc. Roy. Soc. N. S. Wales **10**: **295–297**. 1876.

187. Moss, H. *Macrozamia spiralis*. N. S. Wales Med. Gaz. **2**: 88–89. 1871.

188. Mueller, F. v. Remarks on an undescribed *Encephalartos* from Queensland. Australasian Chem. and Drugg. (Melbourne) **5**: **80–81**. **1883**.

189. Nakamura, S., and Nakajima, B. Nosam kogyo shigen. (Agricultural-industrial resources). Tokyo, **1943**.

190. Nevill, H. The Vaeddas of Ceylon. The Taprobanian **1**: **175–197**. 1886.

191. Nishida, K. Biochemical studies on the sago palm. I. Jour. Agr. Chem. Soc. Japan **10**: **374–378**. **1934**. (Original not seen. Abstr. in Chem. Abstr. **28**: **5097**.)

192. Nishida, K. Biochemistry of Japanese sago plant. III. Jour. Agr. Chem. Soc. Japan **11**: **357–364**. **1935**. (Original not seen. Abstr. in Chem. Abstr. **29**: **6616**.)

193. Nishida, K. Biochemical studies on *Cycas revoluta*. VI. Jour. Agr. Chem. Soc. Japan **12**: **1106–1116**. **1936**. (Original not seen. Abstr. in Chem. Abstr. **31**: **2640**.)

194. Nishida, K., Kobayashi, A., and Nagahama, T. Cycasin, a toxic glycoside of *Cycas revoluta*. I. Bull. Agr. Chem. Soc. Japan **19**: **77–84**. **1955**. (Original not seen. Abstr. in Chem. Abstr. **50**: **13756**.)

195. Norrie, J. S. Examination of the nuts of *Zamia spiralis*. N. S. Wales Med. Gaz. **2**: **57–58**. **1871**.

196. Ochse, J. J. Tropische groenten. Weltevreden, **1925**.

197. Oches, J. J. Vegetables of the Dutch East Indies. Buitenzorg, 1931.

198. Ondaatje, W. C. The starch-producing plants of Ceylon. Technologist **2**: **193–197**. **1862**.

199. O'Shanesy, P. J. Contributions to the flora of Queensland with an epitome of botany for beginners. Rockhampton, **1880**.

200. Palmer, E. On the plants used by the natives of north Queensland, Flinders and Mitchell Rivers, for food, medicine, etc. Jour. and Proc. Roy. Soc. N. S. Wales **17**: **93–113**. **1884**.

201. Parham, H. B. R. Fiji native plants. Polynesian Soc. Memoir **16**: **1–160**. **1943**.

202. Parkinson, C. E. A forest flora of the Andaman Islands. Simla, 1923.

203. Parkinson, R. Dressig Jahre in der Südsee. Stuttgart, **1907**.

204. Parry, E. J. Guns and resins, their occurrence, properties and uses. London, 1918.

205. Peckolt, T. *Cycas revoluta* Linn. in Brasilien. Zeitschr. d. allgem. österreich. Apoth.-Ver. **25**(16): **256–258**. 1887.

206. Penfold, A. R. Useful products of the Australian bush. Tech. Gaz. N. S. Wales **22**(1): 17-24. 1934.

207. Pereira, J. The elements of materia medica and therapeutics. II. 3rd American ed. Philadelphia, 1854.
208. Petelot, A. Les plantes medicinales du Cambodge, du Laos et du Vietnam. III. Arch. des Recherch. Agron. et Pastor. au Viet-Nam, no. 22. 1954.
209. Petrie, J. M. The chemical examination of *Macrozamia spiralis*. Proc. Linn. Soc. N. S. Wales **45**: 424-442. 1920.
210. Phillip, A. The voyage of Governor Phillip to Botany Bay. London, 1789.
211. Pickering, C. Chronological history of plants. Boston, 1879.
212. Planchon, L., and Juillet, A. Etude de quelques fecules coloniales. Ann. Mus. Colon. Marseille II. **7**: 411-562. 1909.
213. Pogge, P. Im Reiche des Muata Jamwo. Berlin, 1880.
214. Poilane, M. Note. Rev. Bot. Appl. et d'Agr. Colon. **4**: 473-474. 1924.
215. Prain, D. Cycadaceae. *in* Prain, D., ed. Flora of tropical Africa **6**(2): 344-354. 1917.
216. Reichert, E. T. The differentiation and specificity of starches in relation to genera, species, etc. Carnegie Inst. Washington Publ. 173(2). 1913.
217. Rein, J. J. The industries of Japan. London, 1889.
218. Reinke, J. Ueber die anatomischen Verhältnisse einiger Arten von *Gunnera* L. Nachr. von d. Königl. Gesell. d. Wissen. u. d. G. A. Univ. zu Göttingen 1872: 100-108. 1872.
219. Reitz, D. Commando. A Boer journal of the Boer War. New York, 1930.
220. Ridley, H. N. The gymnosperms of the Malay Peninsula. Jour. Straits Branch Roy. Asia. Soc. **60**: 53-68. 1911.
221. Riggs, N. V. The nature of a cyclitol isolated from *Macrozamia reidlei*. Jour. Chem. Soc. 1949: 3199-3200. 1949.
222. Riggs, N. V. The occurrence of macrozamin in the seeds of cycads. Australian Jour. Chem. **7**: 123-124. 1954.
223. Riggs, N. V. Glucosyloxymethane, a constituent of the seeds of *Cycas circinalis* L. Chem. and Industry 1956: 926. 1956.
224. Robyns, W. Flore du Congo Belge et du Ruanda-Urundi. I. Bruxelles, 1948.
225. Roig y Mesa, J. T. Plantas medicinales, aromaticas o venenosas de Cuba. Habana, 1945.
226. Roth, W. E. Food: its search, capture, and preparation. Home Secretary's Dept., Brisbane, North Queensland Ethno. Bull. 3. 1901.
227. Rowley, H. The commercial utilization of the "grass tree" (*Xanthorrhoea*) and "zamia" (*Macrozamia*) in Western Australia. Jour. Soc. Chem. Ind. **35**: 290-292. 1916.
228. Roxburgh, W. Flora indica; or, descriptions of Indian plants. Calcutta, 1874.
229. Safford, W. E. The useful plants of the island of Guam. Contrib. U. S. Natl. Herb. **9**: 1-416. 1905.
230. Sarasin, P., and Sarasin, F. Die Weddas von Ceylon und die sie umgebenden Völkerschaften. Wiesbaden, 1893.
231. Sastri, B. N., chief ed. The wealth of India. Raw materials II. C. Delhi, 1950.
232. Savorgnan, M. A. Coltivazione ed industria delle piante tessili con l'aggiunta di un dizionario delle piante e industrie tessili. Milano, 1891.
233. Schneider, A. Mutualistic symbiosis of algae and bacteria with *Cycas revoluta*. Bot. Gaz. **19**: 25-32. 1894.
234. Schuster, J. Cycadaceae. *In* Engler, A. Das Pflanzenreich IV. l. Leipzig, 1932.
235. Schweinfurth, G. The heart of Africa. II. New York, 1874.
236. Schwendener, S. Nochmals über die optisch anomale Reaction des Traganth- und Kirschgummis. Stizungsb. Königl. Preuss. Akad. Wissen. zu Berlin 1890: 1131-1137. 1890.
237. Seddon, H. R., and Belschner, H. G. Poisoning of sheep by the seeds of burrawang (*Macrozamia spiralis*). Agr. Gaz. N. S. Wales **41**: 451-457. 1930.
238. Seddon, H. R., Belschner, H. G., and King, R. O. C. Poisoning of sheep by the seeds of burrawang (*Macrozamia spiralis*). N. S. Wales Dept. Agr., Vet. Res. Rept. 6(1/2): 70-80. 1931.
239. Seeman, B. Viti. Cambridge, 1862.
240. Seeman, B. Flora Vitiensis. London, 1868.
241. Sheriff, M. Supplement to the pharmacopoeia of India. Madras, 1869.
242. Siebold, D. d. Synopsis plantarum oeconomicarum universi regni japonici. Verhandl. Bataviaasch Genootschap v. Kunst. en Wetensch. **12**: 1-74. 1830.
243. Simmonds, P. L. The commercial products of the vegetable kingdom. London, 1854.
244. Simmonds, P. L. The gums and resins of commerce. Jour. Soc. Arts **4**: 13-26. 1855.
245. Smith, J. A dictionary of the popular names of the plants which furnish the natural and acquired wants of man. London, 1882.
246. Smith, J. E. Description of the fruit of *Cycas revoluta*. Trans. Linn. Soc. London **6**: 312-315. 1802.

247. Smith, R. G. The bacterial origin of macrozamia gum. Proc. Linn. Soc. N. S. Wales **29:** 863–868. 1905.

248. Sonohara, S., Tawada, S., and Amano, T. Flora of Okinawa. Mimeo. 1952.

249. Sparrman, A. A voyage to the Cape of Good Hope, etc. I. 2nd ed. London, 1786.

250. Spratt, E. R. The root-nodules of the Cycadaceae. Ann. Bot. **25:** 369–380. 1911.

251. Spratt, E. R. The root-nodules of the Cycadaceae. Ann. Bot. **29:** 619–626. 1915.

252. Standley, P. C. Cycadaceae. *In* Trees and shrubs of Mexico. Contrib. U. S. Natl. Herb. **23:**(1): 47–50. 1920.

253. Standley, P. C., and William, L. O. *Dioon mejiae*, a new cycad from Honoduras. Ceiba **1:** 36–38. 1950.

254. Steiner, P. E. Okinawa and its people. I. Sci. Month. **64**(3): 233–241. II. *ibid.* **64**(4): 306–312. 1947.

255. Stewart, J. D. A report on the disease affecting cattle in the Moruya district. N. S. Wales Dept. Agr. Misc. Publ. 344. 1899.

256. Steyn, D. G. Vergiftiging van mens en dier met giftplante, voedsel en drinkwater. Pretoria, 1949.

257. Steyn, D. G., van der Walt, S. J., and Verdoorn, I. C. The seeds of some species of *Encephalartos* (cycads). A report on their toxicity. So. Afr. Med. Jour. **22:** 758–760. 1948.

258. Stirling, E. C. Anthropology. Part IV *in* Report on the work of the Horn Scientific Expedition to central Australia. Melbourne, 1896.

259. Stuhlman, F. Beiträge zur Kulturgeschichte von Ostafrika. Berlin, 1909.

260. Teijsmann, J. E. Uittreksel uit het dagverhaal eener reis door oost-Java, Karimon Java en Bali Boleling. Natuurk. Tijdschr. v. Neder. Indie **11:** 111–206.

261. Teijsmann, J. E. Dagverhaal eener botanische reis over de westkust van Sumatra. Natuurk. Tijdschr. v. Neder. Indie **14:** 249–376. 1857.

262. Teysmann, J. E. Verslag eener botanische reis over Timor, etc. Natuurk. Tijdschr. v. Neder. Indie **34:** 348–517. 1874.

263. Thomas, N. W. Natives of Australia. London, 1906.

264. Thomson, D. F. The story of Arnhem Land. Walkabout **12**(10): 5–22. 1946.

265. Thomson, D. F. An Arnhem Land adventure. Natl. Geog. Mag. **93:** 403–430. 1948.

266. Thomson, D. F. Economic structure and the ceremonial exchange cycle in Arnhem Land. Melbourne, 1949.

267. Thozet, A. Notes on some of the roots, tubers, bulbs, and fruits used as vegetable food by the aboriginals of northern Queensland, Australia. Rockhampton, 1886.

268. Thozet, A. Notes on some of the roots, tubers, bulbs, and fruits used as vegetable food by the aboriginals of northern Queensland, Australia. *In* Brough Smyth, R. The aborigines of Victoria **1:** 227–233. Melbourne, 1878.

269. Thunberg, C. P. *Cycas caffra*, nove palmae species, etc. Nova Acta Reg. Soc. Scient. Upsaliensis **2:** 283–288. 1775.

270. Thunberg, C. P. Flora Japonica. Leipzig, 1784.

271. Thunberg, C. P. Travels in Europe, Africa, and Asia, etc. I. London, 1793.

272. Thwaites, G. H. K. Enumeratio plantarum zeylaniae. London, 1864.

273. Trimen, H. A hand-book to the flora of Ceylon. IV. London, 1898.

274. Turner, F. The zamia palm (*Macrozamia miquelii* F.V.M.) and its relation to the disease known as rickets in cattle. Agr. Gaz. N. S. Wales **4:** 158–161. 1893.

275. Ueno, S., Matsude, S., and Kimura, T. Constituent of seed oil of *Cycas revoluta*. Jour. Nippon Oil Tech. Soc. **2**(5): 10–15. 1949. (Original not seen. Abstr. in Chem Abstr. **44:** 5618.)

276. van der Walt, S. J. Recent investigations into the toxicity of plants, etc. in the Union of South Africa. Onderstepoort Jour. Vet. Sci. and Animal Ind. **20**(1): 75–83. 1944.

277. van der Walt, S. J., and Steyn, D. G. Recent investigations into the toxicity of plants, etc., no. XV. Onderstepoort Jour. Vet. Sci. and Animal Ind. **21**(1): 45–55. 1946.

278. Verdoorn, I. C. A new species of *Encephalartos* from the Waterburg. Jour. So. Afr. Bot. **11:** 1–3. 1945.

279. Verdoorn, I. C. *Encephalartos villosus.* Flowering Plants of Africa **26:** pl. 1001 and 1002. 1947.

280. Volkens, G. Die Vegetation der Karolinen, mit besonderer Berücksichtigung der von Yap. Bot. Jahrb. **31:** 412–477. 1901.

281. Warburg, O. Das Pflanzenkleid und die Nutzpflanzen Neu-Guineas. *In* Krieger, M. Neu-Guinea. Berlin, 1899.

282. Warburg, O. Monsunia. Betitäge zur

Kenntniss der Vegetation des süd und ostasiatischen Monsungebietes. I. Leipzig, 1900.

283. Watanabe, K. Studien über die Koralloide von *Cycas revoluta*. Bot. Mag. Tokyo **38:** 165–187. 1925.

284. Watson, F., ed. Historical records of Australia. Series I. Governors' despatches to and from England. I. 1788–1796. Sydney, 1914.

285. Watt, G. A dictionary of the economic products of India. II. Calcutta, 1889.

286. Webb, L. J. Guide to the medicinal and poisonous plants of Queensland. Australia Coun. Sci. and Indus. Res. Bull. 232. 1948.

287. White, C. T. *Macrozamia*. Queensland Agr. Jour. **30:** 608. 1928.

288. White, C. *Macrozamia*. Queensland Agr. Jour. **42:** 636. 1934.

289. White, C. Zamia poisonous to stock. Queensland Agr. Jour. **44:** 118. 1935.

290. White, C. A species of zamia. Queensland Agr. Jour. **49:** 397. 1938.

291. Wildeman, E. d. Notices sur des plantes utiles ou interessantes de la flora du Congo. Bruxelles, 1903.

292. Williams, R. O. The useful and ornamental plants in Zanzibar and Pemba. Zanzibar, 1949.

293. Yamafuji, K., Yoshihara, F., and Kondo, H. Ueber die Teilvorgänge der Kohlensäureassimilation. Enzymologia **14:** 30–38. 1950.

294. Yoshimura, K. Chemical constituents of *Cycas revoluta*, Thunb. II. Jour. Tokyo Chem. Soc. **40:** 914–921. 1919. (Original not seen. Abstr. in Chem. Abstr. **14:** 1395.)

295. Yoshimura, K. Ueber einen Ursprung des Stickstoffes bei *Cycas revoluta*. Wissen. Mitteil. Land-u. Forstw. Hochschule Kagoshima **5:** 35–39. 1922. (Original not seen. Abstr. in Bot. Abstr. **14:** 1062.)

296. Yoshimura, K., and Sagava, N. The chemical constituents in *Cycas revoluta* Thunb. I. Jour. Tokyo Chem. Soc. **39:** 1116–1121. 1918. (Original not seen. Abstr. in Chem. Abstr. **13:** 758–759.)

Utilization Abstract

Date Syrup. Dates, the fruits of the palm *Phoenix dactylifera*, consist of a sugar containing pulp and a solid seed or stone. Dates can be consumed fresh, but they can also be used for the manufacture of syrup.

At the request of an interested party in Iraq, experiments have been made with the manufacturing of the date syrup and the utilization of this syrup and of the stones and the extracted pulp.

In the laboratory semi-technical preparation of syrup proved to be possible after the diffusion method (extracting with hot water and concentrating the extracts in vacuum). The composition of the syrup is given in table I and compared with the analysis of a sample received from Iraq. Date syrup proves to be of the invert sugar type; it contains approximately 70 percent invert sugar; the taste is not too sweet.

Consultation with the industry led to the conclusion that date syrup can be used in the manufacture of gingerbread and the like.

In table II the composition of date stones and extracted pulp is given. It seems possible to use the stones and pulp as part of a cattle food, but a final experiment with living cattle could not yet be accomplished. In Iraq feeding trials with sheep have been carried out with macerated dates (dates from which the stones have been removed beforehand), and with ground stones, but only to replace a portion of the ground barley in the ration.

Charcoal from the stones was prepared but did not prove usable in the manufacture of active coal. The high amount of ash (4%) makes it doubtful whether the coal can be used for metallurgical purposes. (English summary, by Ir. W. Spoon, *No. 261 of Berichten van de Afdeling Tropische Producten van het Koninklijk Instituut voor de Tropen. 1957.*)

Potential Utilization of Agricultural Commodities by Fermentation[1]

Use of fermentation products in beverages, foods, feeds and pharmaceuticals is growing steadily, but fermentation production of industrial alcohol, butanol and acetone faces stiff competition from synthetic petrochemicals. In looking to the future of fermentation and its utilization of agricultural commodities, additional experimental approaches should be used in the search for new products, particularly the more complex ones such as antibiotics, enzymes, and vitamins, which in general have resisted economic chemical synthesis.

RICHARD W. JACKSON[2]

With extensive assistance from Eugene S. Sharpe and Roland W. Haines in the collection, preparation and presentation of the data in the charts

Fermentation has long been important in providing outlets for agricultural commodities. The largest and oldest fermentation industries are those which manufacture beer, wine and distilled liquors. Whiskey was a sufficiently large cash crop in 1794 that farmers of western Pennsylvania, Virginia and North Carolina rebelled against the application of an excise tax to their product. In fiscal year 1956, production of beer consumed 105 million bushels of grain; production of wine, 3 billion pounds of grapes; and production of distilled spirits, 46 million bushels of grain, 3 billion pounds of grapes, 3 million gallons of molasses and minor other materials. Altogether these uses constitute the most important fermentation outlet for agricultural commodities.

Fermentation is, of course, widely used in the preparation of food products and in the preservation of green feedstuffs on the farm. For example, in a recent year, 13 billion pounds of milk were used in producing cheese and 53 million tons of feedstuffs in making ensilage. It is our purpose here, however, to focus attention particularly on the commercial aspects of manufacture of product concentrates and chemicals by means of microorganisms. Next to alcohol, lactic acid is the oldest fermentation product in this country, a plant having been established in Littleton, Mass., in 1881. Since then fermentation has been employed in the commercial production of many other chemicals. I should like at this point to sketch out some trends in the last 15 to 25 years, because it is by considering the past and the present that we may gain some partial view of the future. Let us, therefore, look at the size of production and any change in production in the chief fermentation industries, keeping track of the farm products consumed. Grains, sugars, and molasses are the main substrate materials. First consideration should be given to industrial alcohol.

The production and utilization of 95%

[1] Presented Sept. 10, 1957, in New York City at a Symposium on Future Utilization of Agricultural Commodities, Division of Agricultural and Food Chemistry, American Chemical Society.

[2] Fermentation Laboratory, Northern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture, Peoria, Illinois.

ethyl alcohol had reached a hundred million gallons annually before the Second World War. Fermentation was responsible for the bulk of production, and molasses was the chief source. Alcohol from grain amounted to less than 10% of the total. With the advent of war, our production, primarily for use in the manufacture of rubber, skyrocketed and reached a peak of around 545 million gallons in fiscal year 1945. In that year, owing to inadequate supplies of molasses, grain accounted for about 70% of the abnormally high alcohol production. Synthetic alcohol coming into play about 1929 has steadily assumed more and more importance until it was more than half of the total alcohol production in 1950. In 1955, synthetic alcohol was 79%, molasses alcohol 16%, and alcohol from grain only about 2% of the total. Graphs of these changes are presented in Fig. 1.

The course of a second great chemical and solvent industry is depicted in Fig. 2. The total production of normal butyl alcohol and of acetone has steadily increased over 20 years through 1955. Near the end of World War II, fermentation accounted for two-thirds of the normal butyl alcohol and one-tenth of the acetone. The combined amounts from fermentation came to about 150 million pounds per year. Their production required 80 million gallons of molasses or 10 million bushels of corn. By 1950, the total production of normal butyl alcohol and acetone by fermentation had dropped more than half. The decline came as a result, on the one hand, of the competition from synthetic butanol and other synthetic solvents and,

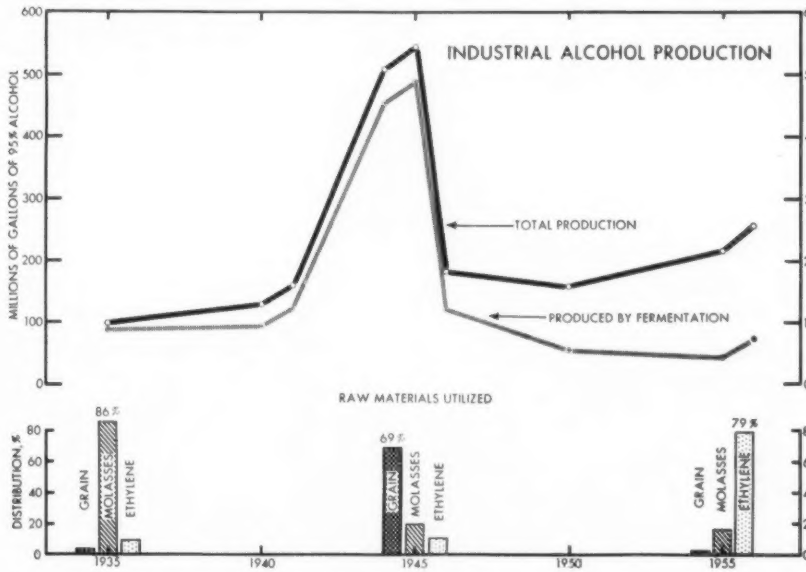

FIG. 1. INDUSTRIAL ALCOHOL PRODUCTION

Data obtained from Reports of the U. S. Treasury Department, Alcohol and Tobacco Tax Division of Internal Revenue Service. Years are fiscal years—not calendar years.

on the other hand, of increasing prices for molasses.

Many of the competitions and problems of the alcohol fermentation industry are similar to those of the butyl alcohol–acetone fermentation industry. Again, both are supported to considerable extent by valuable feed byproducts. Inasmuch as the technology of both industries has already been perfected by research in many directions, relief for both resides in a cheaper carbohydrate—somehow. For many years, molasses has been their main substrate material, their cheap source of carbohydrate. Now, when they need cheap molasses more than ever, they are forced to compete with a big new customer—the cattle feed market. Fig. 3 shows the utilization of molasses in the United States over an 11-year period from 1946–56. The amount of molasses available from all sources increased from 264 million gallons in 1946 to more than 600 million gallons in 1956. The greatest area of the chart represents molasses incorporated in feeds, starting at 78 million and reaching a maximum in 1955 of 419 million gallons. The peak use of molasses in making industrial alcohol was 180 million gallons in 1953, dropping to 90 million in 1956. Molasses for manufacture of butanol and acetone amounted to 40 million gallons in 1946 but was still about 35 million gallons in 1955 and again in 1956. Forty to seventy million gallons of molasses were used annually to make yeast, citric acid and vinegar.

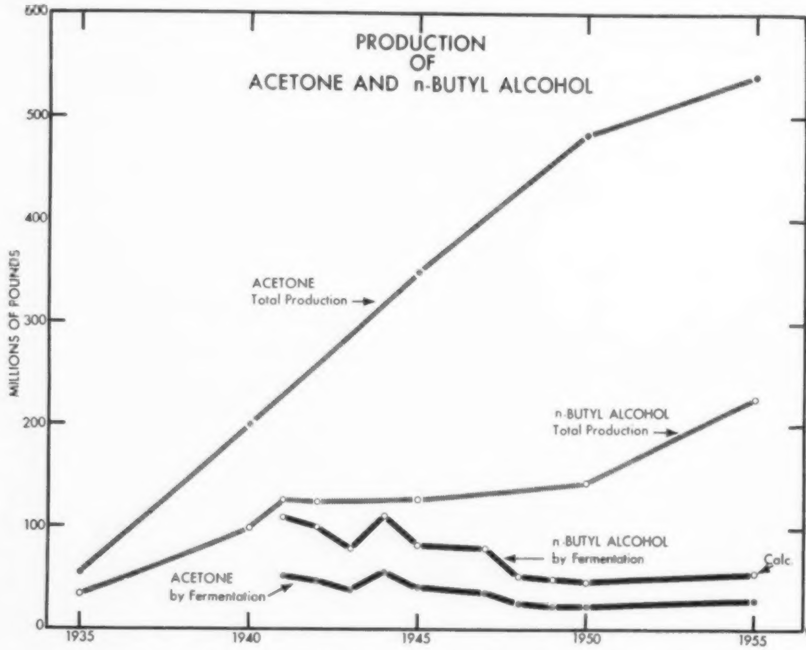

FIG. 2. PRODUCTION OF ACETONE AND n-BUTYL ALCOHOL

Most of the data taken from annual Reports of U. S. Tariff Commission on Synthetic Organic Chemicals. Some figures obtained from review articles.

The price of blackstrap molasses following the Second World War was as high as 28 cents per gallon, held at 10 to 11 cents from 1953–55, and then advanced last year to 22 cents which is the approximate price now. The cost of the sugar in molasses has gone from around one cent per pound before the War to $3\frac{2}{3}$ cents at the present time. Hi-test molasses has advanced accordingly and has been reported unavailable in recent months even at the high price. Although it appeared that molasses for the alcohol and butanol industries had practically dried up, announcement was made some weeks ago that a fermentation company in the United States had contracted for 60 million gallons of Cuban blackstrap from this year's crop and 100 million gallons from next year's crop. The price was $10\frac{1}{4}$ cents per gallon. The sole use is for manufacture of alcohol. Thus, the fermentation alcohol business continues.

The best known organic acids produced by fermentation are citric and lactic acids. Data on production of these two acids are given in Fig. 4. Nearly all citric acid is made by fermentation; none is synthesized. Fermentation production has grown rapidly from a small beginning in the 1920's. Total annual production has grown to 50 or perhaps 60 million pounds for 1955. The manufacture of lactic acid has remained fairly

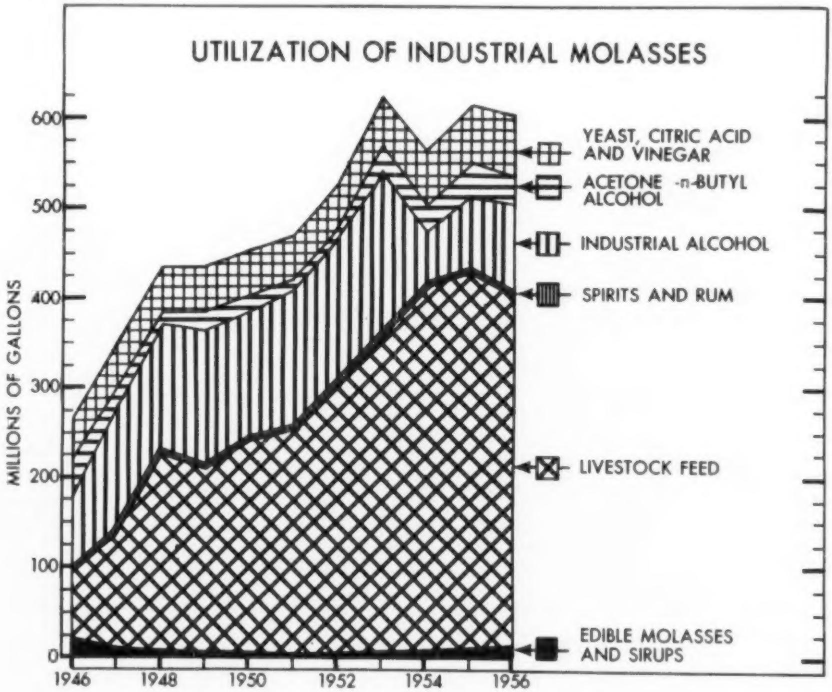

FIG. 3. UTILIZATION OF INDUSTRIAL MOLASSES

Data from Table 3, p. 17 of "Industrial Molasses", an Annual Marketing Review for 1956, Agricultural Marketing Service, U. S. Department of Agriculture (January 1957).

constant for many years. Annual production increased to more than 8 million pounds during the War but settled back to five and a half million in 1955. It is estimated that manufacture of gluconic acid in various forms, all by fermentation, has increased to 4 million pounds primarily as acidulants in foods and drinks and their consumption will doubtless continue to grow with the population and with greater dependence on prepared foods. Other fermentation acids, related to the naturally occurring sugars, have yet to be exploited in this field. Two-

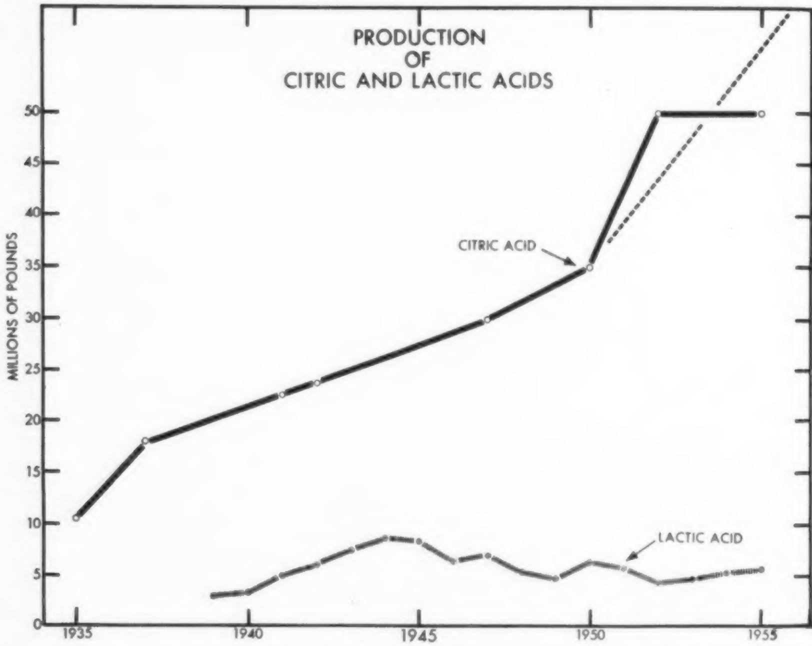

FIG. 4. PRODUCTION OF CITRIC AND LACTIC ACID

The first four plotted figures on citric acid are from Reports of the U. S. Treasury Department; the remaining four are estimates by various authors. The broken line inserted at the end of the graph on citric acid gives a more optimistic and probably a more accurate conception of citric acid production during recent years. The data on lactic acid up to 1945 are from a special report, November 10, 1950, of U. S. Department of Commerce. Figures for 1945 and subsequent years are from the annual Reports of the U. S. Tariff Commission on Synthetic Organic Chemicals.

annually. Several million pounds of fumaric acid are also reported to be made by fermentation each year.

Future markets for the acids will depend on holding and expanding present uses and on developing new applications. Citric and lactic acids and acetic acid in dilute solution, i.e., vinegar, are used ketogluconic acid has received more than passing interest from the food industry because, like ascorbic acid, it is a reducing agent. A second group embraces citric, fumaric, itaconic and lactic acids whose esters are or may be used as plasticizers. A third group can be used in alkyd resins by virtue of two or more

carboxyls. In this group fall fumaric, itaconic and citric acids. A fourth group comprises the unsaturated fumaric and itaconic acids which as acids or esters are amenable to incorporation in acrylate type polymers. A fifth group of acids is valuable as sequestrants; examples are citric, tartaric and gluconic acids. Indeed, this use appears to exceed all others for gluconic acid. The S. Tariff Commission as shown in Fig. 5. Figures for 1955 are: ascorbic acid, 2,354,000 pounds; riboflavin, 311,000 pounds; and vitamin B_{12}, 488 pounds. The 488 figure seems very small but its value is high—around $60,000 per pound, or rather pound equivalent, since most of the vitamin is sold in diluted form. It is pointed out that only one step of the ascorbic acid manufacture is fermen-

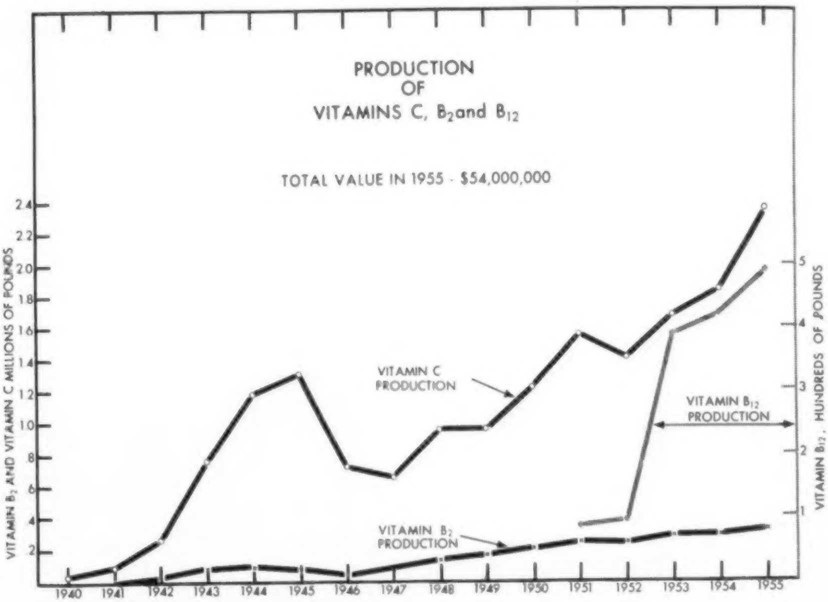

FIG. 5. PRODUCTION OF VITAMINS C, B_2, AND B_{12}

Data obtained from annual Reports of the U. S. Tariff Commission on Synthetic Organic Chemicals.

plasticizer-plastics outlet offers great additional opportunity for fermentation acids if prices can be brought low enough to compete more effectively with those of the chemical industry. Kojic and α-ketoglutaric are examples of acids for which applications may yet be found and respectable markets developed.

Purified vitamins and vitamin concentrates, produced in whole or in part by fermentation, are reported by the U. tative, and that part of the riboflavin production is synthetic. Large amounts of miscellaneous vitamins are also produced and utilized in a secondary fashion, e.g., in distillers' solubles and in recovered brewers' yeast—not to mention those produced fermentatively in the two sulfite liquor–yeast plants in Wisconsin. Fig. 5 reveals that the production of riboflavin and ascorbic acid has doubled in the last 5 or 6 years while

that of B_{12} increased five-fold in a shorter time. The feed outlet has been expanding.

Sale of enzyme preparations for commercial use, exclusive of malt, was estimated to total 20 million dollars for 1955. A considerable portion is derived from microorganisms, but we do not have available precise data as to pounds produced or as to pounds of agricultural commodities employed in their manufacture. An estimate of the principal commodities used for the production of vitamins, enzymes and antibiotics as a group will be introduced later.

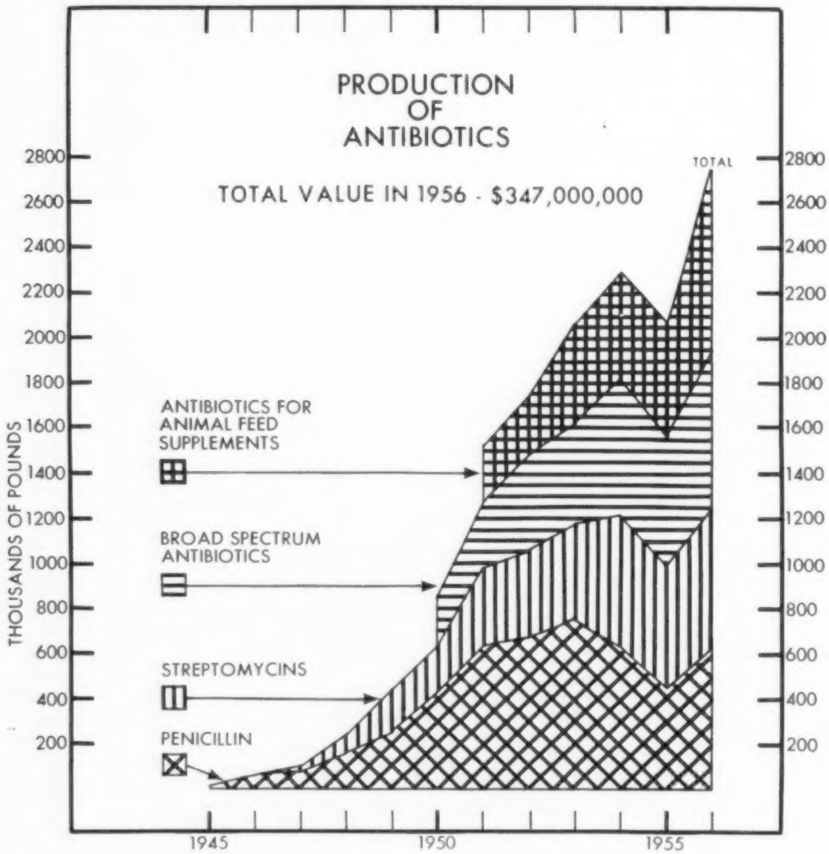

FIG. 6. PRODUCTION OF ANTIBIOTICS

Data obtained from annual Reports of the U. S. Tariff Commission on Synthetic Organic Chemicals.

The antibiotics industry, as most of us know but tend to forget, is little more than 10 years old. Even so, and despite the great decline in the price of penicillin, the industry's annual product has a wholesale value of about 350 millions. Fig. 6 shows its cumulative growth ex-

pressed in pounds of the principal antibiotics. The grand total in recent years is over 2 million pounds. The commodities used to make the antibiotics are many times this amount, thus constituting an important outlet for agriculture; yet the commodities used are not as large as we would like—relative to the medical and monetary importance of the antibiotics industry. The production of antibiotics for all purposes, as shown by the top graph line in the chart, has grown steadily. There was a dip in 1955 but the figures for 1956, which just became available, show continuing rapid expansion in all categories. It seems probable that there will be further development of antibiotics for industrial scale use against plant disease.

Utilization of agricultural commodities in fermentations discussed thus far is summarized in Fig. 7. If the 255 million gallons of industrial alcohol produced in fiscal year 1956 had all been made from blackstrap molasses, 588 million gallons would have been used; if from grain, 100 million bushels. Likewise, if the 225 million pounds of *n*-butyl alcohol produced in 1955 and a corresponding amount of acetone had all been made from blackstrap molasses, 186 million gallons would have been used; if from grain, 24 million bushels. Actually, only 141 million gallons of molasses and one

ANNUAL UTILIZATION OF AGRICULTURAL COMMODITIES BY FERMENTATION

	ACTUAL USE		IF ALL PRODUCTION WERE ENTIRELY FROM -		
BEVERAGE INDUSTRY (alcoholic) (F.Y. 1956)	Grain Molasses Grapes	151 million bu. 2.8 million gal. 6 billion lbs.			
	GRAIN bushels	MOLASSES gallons	GRAIN bushels		MOLASSES gallons
INDUSTRIAL ALCOHOL (F.Y. 1956)	1.3 million	105 million	100 million (est.)	or	588 million (est.)
ACETONE and n-BUTYL ALCOHOL (1955)		36 million	24 million (est.)	or	186 million (est.)
ORGANIC ACIDS (1955-56)					
Citric, Lactic, Fumaric	3 million (est.)	or 15 million (est.)			
Gluconic, Acetic	125 thousand (est.)				
VITAMINS, ENZYMES, ANTIBIOTICS (1955)	10 to 15 million (est.)				

FIG. 7. ANNUAL UTILIZATION OF AGRICULTURAL COMMODITIES BY FERMENTATION

Most of data taken or estimated from Reports of the Alcohol and Tobacco Tax Division of the U. S. Treasury Department and the U. S. Tariff Commission. Figures on production of citric acid, fumaric acid and gluconic acid and on enzymes, used for estimating substrate materials, were from other sources.

or two million bushels of corn were used annually in the two industries in 1955 or 56. At the same time, 400 million gallons of molasses which might have been used in fermentation went into cattle feed, displacing more than 60 million bushels of grain which was added to the surplus.

The President's Commission on Increased Use of Agricultural Products and its task groups on grain and on alcohol investigated the fermentation field extensively. It was found that the capacity of idle industrial alcohol plants was 218 million gallons of 95% alcohol per year equivalent to 87 millions bushels of grain. Indeed, production capacity could be stepped up to 250 million gallons equivalent to 100 million bushels of grain. The Commission received and published estimates showing that corn would have to be supplied at 50 cents or less per bushel to bring fermentation alcohol into the cost range of synthetic alcohol. The Commission considered motor fuel, polyethylene plastic and butadiene for synthetic rubber as outlets, looking for the most feasible and least uneconomic.

Motor fuel was not recommended as an outlet for alcohol from grain. Alcohol no longer has premium blending value since the octane ratings of commercial motor fuels have been increased so greatly. The alcohol at best would have to compete with bulk gasoline at 13½ cents a gallon. This corresponds to a loss of 6½ cents per bushel without any payment for the grain. And there are many difficulties in arranging satisfactory blending and distribution to the public.

Alcohol derived from grain was found to fare little better economically as a source of ethylene for manufacture of polyethylene. Competition from the petrochemicals industry is such that corn would have to be delivered free at the alcohol plant.

The Commission's conclusion was that, of all possible industrial outlets available for fermentation alcohol at this time, conversion to butadiene would be the least costly. Moreover, this outlet involving, as it does, a rapidly expanding synthetic rubber industry would entail the least dislocation. The Government has an interest in two butadiene plants with maximum intake capacity of 229 million gallons of alcohol equivalent to 84 million bushels of grain. The plants could be put into operation over a period of 2 to 6 months. The return for corn was estimated to range from 11 to nearly 50 cents per bushel. At the then current price of 15 cents a pound for butadiene, alcohol at 23.4 cents could be used for production. Under these conditions, the corn would net about 26 cents per bushel. Some assumptions are involved in these calculations and exact economics would have to be determined by plant operation. The Commission did not recommend that the alcohol-butadiene-rubber outlet for grain be implemented. It simply set forth the facts and figures for this outlet as being the best of three possibilities.

The butyl alcohol–acetone fermentation industry originally used corn but in recent years has depended on molasses. Now butyl alcohol and acetone can be manufactured more cheaply from gas streams than from either grain or molasses at their going prices. It is estimated by the Commission, however, that 8 to 12 million bushels of corn could be used in this industry annually if corn were furnished at 60 to 70 cents per bushel. Another 6 to 10 million bushels of corn could be employed under these conditions to supply the export market. The corn need not be top-grade.

A new field, little exploited to date, is that of microbial polymers. The only example of actual production on a fairly large scale is that of dextran. It has been manufactured chiefly as a blood

plasma expander but has other uses as a thickener in food products and as an additive to oil-well drilling muds. It can be made by fermenting sucrose or molasses with *Leuconostoc mesenteroides* or, preferably, by utilizing the powerful extracellular enzyme secreted by the organism. Although the total domestic production to date is of the order of only a million pounds and although peacetime applications have developed slowly, dextran serves to illustrate possible development of the microbial polymers as a whole. Surveys of microorganisms and their products have shown that there are dozens or hundreds of polymers, mostly carbohydrate in nature, which need to be investigated. They exhibit an interesting range of properties: high viscosity, low viscosity, elasticity and film formation. Again, if suitable cheap enzymes can be prepared from microorganisms, they can be used, like dextransucrase, to bring about radical transfer and production of valuable homopolymers, such as amylose. The substrate can conceivably be maltose or even starch as well as sucrose.

The present market for special imported commercial gums, such as arabic and tragacanth, is about 48 million pounds per year, selling at 16 to 98 cents per pound. Similarly, over seven million pounds of seaweed polymers, such as agar and algin, are produced and sold at one to four dollars a pound. The annual output of cellophane is 160,000,000 pounds, selling at around 40 cents. These are examples of large-scale applications that come about when price and properties are propitious. There is no question that microbial polymers of interest can be produced. The major questions are whether such polymers can be produced in high enough yield and at low enough cost to meet competition. Only research can give the answers.

Before leaving the polymer subject, I should like to devote some attention to a special case—namely, that of rubber. In view of its wide distribution in plants, perhaps 10% of the total, one should not be surprised by its occurrence in some of the microorganisms. Investigation in this field has been limited. Dr. W. D. Stewart, working first in the laboratories of the B. F. Goodrich Co. and later under a Naval Research Contract at the Atlantic Research Corporation, Alexandria, Virginia, showed that several species of *Lactarius* and one of *Peziza* contained up to 1.7% of rubber on the dry basis. The material analyzed was the sporocarp, the macroscopic mushroom body which grows in the ground. When the organism was grown in submerged culture, the mycelium also yielded rubber although only a few hundredths of a percent, again dry basis. Infrared analysis proved the rubber to be *cis* 1,4-polyisoprene, of the same structure as that of rubber from *Hevea brasiliensis*.

I shall digress a moment here to discuss another substance which is mostly hydrocarbon, namely, fat. The production of ordinary fat or closely related materials from carbohydrate has never appeared to the writer as an economically feasible probability. It is known, of course, that several microorganisms are good fat producers and very likely the yields could be raised by the usual means. Even so, the conversion of carbohydrate to fat involves essentially the conversion of $-CHOH-$ to $-CH_2-$. Two parts by weight shrink to one. If the sugar cost only $3\frac{2}{3}$ cents a pound and if two-thirds of the theoretical yield were obtained, the starting material for a pound of product would be 11 cents, whereas soybean oil now sells at 11 to 12 cents per pound. These considerations by no means rule out the production of a fat or related material having special properties and therefore bringing a special price. A unique fat, high in unsaturated fatty acids, for use in new diets to prevent arteriosclerosis, might be such

a special case. The versatile microorganism might be able to construct chemically the fat best suited for this purpose.

While rubber is a hydrocarbon rather than a fat, about the same theoretical weight loss is entailed when carbohydrate is the starting point. At the same time, natural rubber commands a price of 30–35 cents per pound and the market, despite the great expansion of synthetic rubber production, has been steady at about 600,000 long tons per year—all imported. This is a tremendous market. If a yield of 7 pounds of rubber were realized from a bushel of grain, 100 million bushels of grain would be required to produce 320,000 long tons of natural rubber annually—a little over half of our imports.

As the charts show, considerable amounts of vitamins and antibiotics produced by fermentation are used in feeds. Nevertheless, with regard to volume of feed product and amount of agricultural commodity consumed, greater opportunities appear to lie ahead. I refer particularly to the microbiological production of amino acids, amino acid concentrates, or proteins, for use in farm rations. Several companies are already making lysine, methionine and tryptophane by chemical methods, and one company is manufacturing lysine by fermentation. Our own approach to supplying the amino acids needed for optimal protein quality in animal feeds has been to search for microorganisms containing protein with a high level of lysine or methionine. We estimated that the content of the given amino acid should be 20% or higher in order to give the required leverage in supplementing the prevailing grain ration. If the leverage is not great enough, an excess of unwanted amino acids is obtained before sufficient lysine or methionine is incorporated. There are numerous examples among both animal and plant proteins containing more than 20% of one amino acid. The microorganisms possessing great versatility in the synthesis of chemical compounds and ranging through many thousands of different species appeared to be a good place to look for the needed protein. About half of the dried cells of bacteria, molds and yeasts is protein. Organisms would have to be produced whose dried product was free of toxicity and at the same time digestible. If such were the case, the supplementing amino acid should be more effective inasmuch as it would be cleaved and made available gradually along with the other amino acids throughout the whole 24 hours of the day. The amino acid which is all free from the start runs the chance of rapid absorption and metabolic dissipation of any excess not needed at the moment.

A few years ago, Dr. H. H. Hall of our staff and I calculated the amounts of lysine, methionine and tryptophane needed to bring the rations then used up to the requirements recommended by the National Research Council. This projection was made for both poultry and swine which together consume 75 million tons of feed annually. It was calculated that several hundred thousand tons of lysine and methionine were needed in addition to the amounts present in the existing rations. Even 100,000 tons occurring in protein at a 20% level would require 100 million bushels of grain for fermentative production. Admittedly these calculations involve assumptions and approximations, but certainly they point to a large potential volume of fermentation product which might one day be brought into play.

Although the emphasis in this review is purposely placed on materials for industrial use as chemicals and feedstuffs, it should be stated that there is room for further development of fermented foods.

In looking to the future of fermentation and its potential utilization of agri-

cultural commodities, we must inquire as to what are the best ways of discovering new useful fermentative products and processes. The many hundreds of substances discovered to date and their great variation in structure tell us that there must be many more hundreds to be discovered. There is no doubt that screening many different groups of microorganisms will unpredictably but continually turn up new compounds. Many of our present fermentation industries have developed out of more or less accidental discoveries. In recent years practical fermentation research has veered much more definitely toward selected objectives such as, for example, a rich source of vitamin B_2 or B_{12}, the production of a steroid with a hydroxyl group in the 11 position, or the synthesis of lysine from simpler materials. The question which I wish to raise here is whether it may not prove possible in the future to start from scratch and to discover microorganisms, or enzyme systems derived from microorganisms, which are capable of synthesizing a specified compound—not known previously to be produced by microorganisms.

It is a reasonable postulate that all the products of biosynthesis in plants, animals and microorganisms are susceptible to degradation by microorganisms taken as a whole. Enrichment culture applied to the flora of the soil often leads to the isolation of one or more organisms capable of degrading a given organic compound. The discovered organism contains the necessary degradative enzymes; it may also contain the necessary elements of the corresponding synthetic system. Lieberman and Kornberg were able to discover an organism which degrades orotic acid, and later, after analyzing the enzyme systems involved, to reverse the degradative action and fermentatively synthesize orotic acid starting from simpler compounds. Can such techniques be extended to bring about the fermentative synthesis of wanted compounds starting with the sugars, amino acids and lipids, which occur in agricultural materials? Another technique of great interest and awaiting practical development is the use of mutation, as demonstrated by Beadle, Bonner and Tatum, not just to improve the yield of a product already in sight, but by gene alteration to let transient metabolites accumulate in quantity. Some of these should have commercial use. These are possibilities over the longer term, and I think that they will probably be realized. Fermentation should become more versatile and more important in the useful disposal of agricultural crops.

Future Utilization of Cereal Crops[1]

Estimates made on the uses for cereals (corn, wheat, oats, barley, sorghum, rice, and rye) in 1975 are based upon a number of assumptions. If those made in this article are approached, the pattern of cereal use will be much the same as it is at present.

REID T. MILNER

Department of Food Technology, University of Illinois, Urbana, Illinois

In discussing the future utilization of cereal crops it might be more interesting to launch at once into science fiction and attempt to visualize cereal utilization in 2957. In an attempt to stay away from fiction the future of cereal crop utilization will be discussed only as it may be developed during the next 15 to 20 years. To make this modest excursion into probable uses for these coming years, it will be necessary to survey utilization in the immediate past and the present as well as to consider the factors which may direct uses of these crops in the near future.

In using the term cereal crops, I am referring to corn, wheat, oats, barley, sorghum, rice, and rye. Even the smallest of these crops has been grown on over 1½ million acres of land every year since 1940, but there is a marked difference in the amounts produced. All figures quoted will be in short tons unless otherwise specified. The customary references to bushels may be somewhat deceiving in comparisons, since a bushel of oats is 32 lb. while one of wheat is 60. The average tonnages produced yearly in the last 17 years in the United States are for corn 85.2 million, for wheat 32.2 million and for oats 20.7 million. In this same period the maximum production of barley has reached 10 million tons, of sorghum 6 million, rice 3.2 and rye 1.5. It is apparent that the amount and importance of corn, wheat and oats are much greater than of the other small grains. The remainder of this discussion will be limited to these three major cereals.

Figure 1 shows the production, in millions of tons, of corn, wheat and oats for the years 1940–1956 inclusive (1). The shaded portion shows the largest single domestic use for the particular crop. With corn and oats this use is livestock feed; with wheat it is human food. Since all three crops are shown on the same scale, it is easy to see the overwhelming importance of corn. In general, the fluctuations from year to year in production are greater than changes in the chief use for each crop. Also it is evident, as might be expected, that fluctuations in production are considerably greater for corn than for the other two cereals.

In the case of corn, the other principal uses representing the difference between the total production and the amount used for feed as shown in Fig. 1 are for dry milled products, wet milled products, distilled spirits, seed and exports. Over the years shown, with a few exceptions, the production of dry milled products has been relatively constant, wet milled products have increased somewhat, spir-

[1] Presented at the American Chemical Society meeting, September 10, 1957. Division of Agricultural and Food Chemistry, Symposium on Future Utilization of Agricultural Commodities.

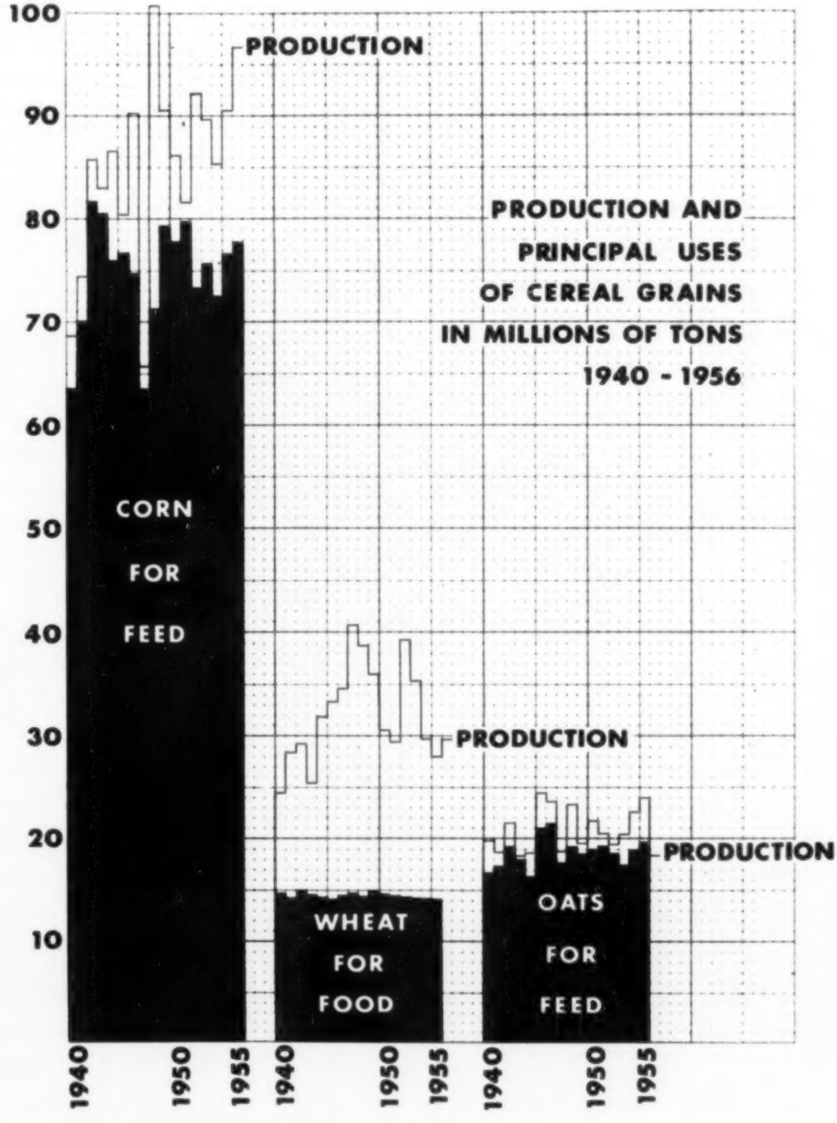
PRODUCTION AND
PRINCIPAL USES
OF CEREAL GRAINS
IN MILLIONS OF TONS
1940 - 1956
PRODUCTION
PRODUCTION
PRODUCTION
CORN
FOR
FEED
WHEAT
FOR
FOOD
OATS
FOR
FEED
100
90
80
70
60
50
40
30
20
10
1940
1950
1955
1940
1950
1955
1940
1950
1955

Fig. 1.

its and seed remained essentially unchanged and exports of course have fluctuated widely. Another "use" for the corn produced has been storage and the carryover which has increased each year recently.

With wheat the remarkable fact is that the amount used for domestic food remained constant over the years. It is purposes. The wide and fluctuating differences between production and consumption for food have led to very large stored stocks.

For oats both production and consumption for feed have fluctuated relatively little. Use for breakfast food has declined somewhat since the war years but has remained fairly constant for the

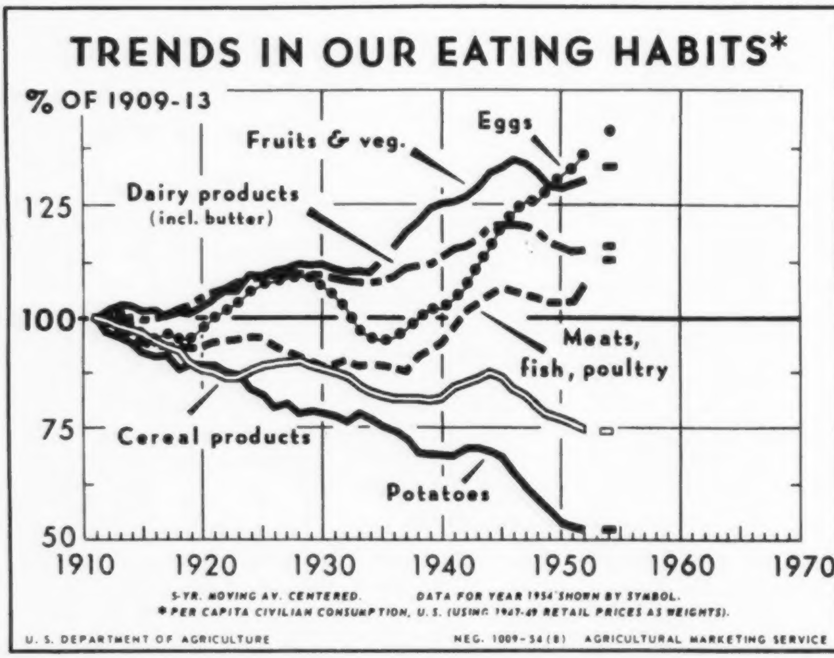

Fig. 2.

evident that the steady and surprisingly high rate of population increase in the United States has been accompanied by an equally steady decrease in per capita consumption of wheat products. As Fig. 2 shows, the decrease in consumption of cereals in general has been accompanied by an increased use of meat (2). Other consumption of wheat has been for seed, feed and export with a very small amount used for industrial past 7 years as has the use as seed. Carryover of oats has also been relatively constant and is much less than for corn and wheat.

Graphs or charts of the livestock population or meat production in the United States would have paralleled in general the use of corn for feed because corn is a major feed ingredient. Indirectly, and insofar as the pork, beef and chicken fed on corn are later eaten, the largest sin-

gle end use of corn is ultimately for human food. The trend toward increased consumption of meat has persisted over a number of years and apparently the rate of increase is becoming greater (Fig. 2). General prosperity and an increasing annual income are major factors in allowing Americans to indulge their taste for meat. The increase in population is the third factor which in combination with high individual income and general prosperity should provide even larger markets for meat, and hence for corn, in the future (3). Against this trend, however, must be set the increased efficiency of animal diets as now developed. The ratio, pounds of meat per pound of feed, has been markedly increased recently and will increase more in the future. Therefore, predicting the future amount of corn used as feed is not a simple extrapolation of population growth and food trends. It seems conservative to predict however that at least as much and probably more corn will be needed for feed purposes 15 to 20 years in the future.

Serious competition for corn as a feed may be furnished in the future by both barley and sorghum. Although all the cereals have been used as feed for centuries and the study of animal nutrition has found much about the relative feed values of these grains, new discoveries are still being made. Work on anti-metabolites or anti-growth factors as well as accessory nutrients indicates that simple treatment may markedly improve some grains. For example steeping barley is reported to increase its feed value. The kinds of cereals used for feed will also be affected by the location of future markets. Population is shifting westward at an increasing rate. As transportation costs increase, it will become necessary to produce feed and provide the consumer with meat with a minimum of transportation in the process. Sorghum, barley and even wheat may prove to be serious competitors of corn in the west, especially in the northwest.

Food use of cereals faces many obstacles which may limit an increase in the future. The present campaign against obesity frequently singles out starchy materials as major offenders. Advances in food technology, particularly in the preservation and storage of more perishable foods, will provide increased competition for the cereals. The ready availability of canned, frozen and fresh fruits and vegetables in the United States has contributed in the past to the decrease in consumption of cereals per person. As these products become more generally available elsewhere, exports of cereals and cereal products may be less desired. On the other hand, growth in population will require more cereals for food. Likewise, the value of the energy, essential amino acids, vitamins and minerals found in cereals is well recognized and insures that cereals will always have a large place in a well designed diet. The same advancing food technology which has benefited fruits and vegetables has also developed the freezing of cereal products to preserve freshness. Bread can now be baked continuously and frozen almost as it leaves the oven. This new technology permits lower labor cost, greatly improved keeping and reduction of staling, and allows the leveling of the work load for bakeries. A five-day week and no overtime work before holidays now appear possible. It is reported that the long slow decline in per capita consumption of cereal products has halted. If the current anxiety about excess fat in the diet is translated into action, it will probably assist cereals to retain or even slightly increase their present consumption per person. Such a development will favor wheat and in 1975 may require a 33 percent increase in wheat for food above present requirements to feed our increased population.

Before looking further at the future

utilization of cereals some attention must be given to possible changes in the cereals themselves. Plant breeders have performed near miracles in the past with commercial double cross hybrid corn and rust resistant wheat as demonstrations of their ability. Much research has been completed and more is under way to produce basic and major changes in the composition of the cereals. The composition of corn on a dry basis has averaged in recent years about 70% starch, 10% protein and 4.5% oil. Different varieties and different growing conditions can alter these averages within rather wide limits. By selection (and breeding), however, it has been possible to produce corn with a protein content as high as 19.5% or as low as 4.9%. Likewise, corn has been obtained with oil as high as 15.4% and as low as 1.0% (4). The starch of ordinary corn is composed of two fractions, amylose and amylopectin, distinguished as straight and branched chain polymers. In waxy maize, instead of about 25% amylose and 75% amylopectin as found in ordinary corn, we have 100% amylopectin. The corn breeders have been successful in producing strains containing as much as 70 to 80% amylose. Some breeding work has been reported on changes in the amino acid composition of corn to produce a higher content of lysine and tryptophane (5).

It is possible that the future utilization of cereals will depend largely on the development of these special variants from the corn, wheat and oats that are known today. It seems clear that corn containing, for example, 20% protein and 15% oil would require different processing and find different uses from those now prevalent. However attractive this line of thought may be, it is evident that corn as a source of oil or protein or both for industrial use must face formidable competition from the crops now yielding these products such as soybeans, peanuts and cottonseed. Cost of production and yields will determine the winner in this agricultural competition. Unless the protein or the oil from corn has special, desirable properties or is required for some specific use such as zein for fibers, it seems unlikely that corn will ever be grown and processed primarily as a source of oil or protein. The same is true for wheat and oats. In the case of both of these grains, it is almost certain that the protein contents can be increased by breeding, but until the protein acquires special value, there seems little prospect for its use for new purposes. These comments do not apply to the improvement of corn as a livestock feed by increasing its protein content. Knowledge of animal nutrition is increasing, and the use of electronic computers for evaluating economic factors in farming is becoming more developed. It should be possible to determine whether protein in livestock feeding can be furnished more cheaply from oilseed meals or high protein corn. If high protein corn is the better feed, an even greater portion of the crop than at present will be used for this purpose in the future.

Alterations in the character or type of starch are in another category. Many uses are known or proposed for amylose, and only the cost of separating it from amylopectin hinders search for other uses. Waxy corn is being grown in increasing amounts for food purposes where special properties of the starch have value. Development of a commercial corn hybrid with starch containing only amylose would result in new nonfood outlets for corn. Since corn and wheat starch can be used interchangeably for most purposes, development of a wheat amylose by genetic work also appears possible. Again the cost of production and processing seems to favor the chances for corn as compared with wheat. In the future utilization of cereal crops, therefore, the development of a

new "amylose" corn specifically designed for industrial starch purposes and further expansion of the present production of waxy corn for food purposes seem probable. Other major changes in the composition of the cereals appear now to be unlikely in the next 15 to 20 years.

Attempting to estimate the future utilization of cereal crops for new purposes is most difficult. Extrapolation of present uses into the future has involved guessing the future national income, world trade and stability and the progress to be made in agronomic and genetic research. The development of new uses on a relatively large scale depends not only on these factors but on progress in chemical and engineering research and invention in other fields. The unfortunate individual who would have predicted the future utilization of petroleum in 1910 based on its past uses is an example of the dangers of such forecasting. Within a relatively few years the major use changed from kerosene for illumination and heating to gasoline for motor fuel. This same individual, however, could have made an excellent guess as to the future uses of coal at the same time that he missed on petroleum. There is a chance, therefore, that cereal crops may at this time resemble petroleum in 1910 and an equal chance that the cereal use pattern will change as little as that of coal did betwen 1910 and 1925.

Since the largest single constituent of cereals is starch, new uses for starch will lead directly to new uses for cereals. The Task Group on Industrial Use of Grains (Other Than Alcohol) of the President's Bipartisan Commission on Increased Use of Agricultural Products has conducted a careful study of potential uses (6), and in their report a large majority of their research proposals relate to starch. The production of starch from corn, wheat and sorghum is now a commercial operation on a large scale and is capable of expansion without further development. The problem in simplest terms is to decide what are the most probable new uses to be found for starch and which of the cereals will furnish the starch.

Starch is a glucose polymer with marked similarity in structure and composition to cellulose. At present starch finds extensive use as an additive both in paper making and textile weaving. The proposal to combine chemically starch with cellulose fibers to form new types of paper and textile products therefore looks entirely feasible. Such molecular combinations could have very different properties and uses from paper or cotton fabric with starch finishes. Nevertheless, the present large scale production of paper and cotton textiles provides a range of products with diversity of uses into which starch-cellulose could easily fit.

Linking of starch and cellulose involves two materials chemically similar. The polymer chemists have recently begun synthesizing block and graft co-polymers. These co-polymers are a relatively coarse mixture and may display some of the original properties of each of the starting materials rather than an average of the two. If successful linking of hydrocarbon polymers with starch can be accomplished, many of the present weaknesses in starch can be overcome. As in the case of cellulose, the successful combination of starch with some of the presently used plastics may make available a potentially large market, for example in the building industry. Resistance to moisture, insects, and microorganisms would need to be obtained from the materials used with starch.

Another future use for starch could result from its effect on surface properties of other materials and its colloidal properties. Modified starches seem to have possibilities as flotation agents in the purification of ores, in water treatment and in modifying the structure of soil. All three of these fields are expanding,

and the processes now used must be improved. As high grade ores are exhausted, as is the case with domestic iron ore, material with a lower metal content must be used. Such low grade ores need concentration and partial purification before smelting. Water shortages and increasing pollution of present supplies are requiring expanded treatment. Improvement of soil texture by chemical additives has been demonstrated, but the cost of present chemicals has prevented the large scale application of these methods.

The Corn Wet Milling Task Group (7) has reported the potential use of as much as 36 million tons of corn to produce starch for the above purpose. This is about 8 times the present wet-milling capacity and over 9 times the 1956 grind by wet mills. As has been emphasized, these new uses are all dependent on the success of research which still has far to go. Extraction of this starch from corn by present processes would require a plant investment of about 4 billion dollars and in addition would involve the marketing of tremendous quantities of by-products. It seems possible that within the next 15 to 20 years, the present wet milling industry, which has shown a steady growth over the last 17 years, could double its present capacity and thus handle nine million tons (320 million bushels) of corn each year. Moderate success in starch research may permit operation at full capacity of these enlarged facilities.

Similar speculations could be made for wheat, oats and the other minor cereal crops or for other cereal uses involving dry milled cereal products and uses for fermentation. It seems probable, however, that none of these has the promise for new uses displayed by corn starch in the areas discussed. Since starches from all cereals are largely interchangeable, any development in corn starch markets would also materially help these cereals.

Estimates on the uses for cereals in 1975 are based upon a number of assumptions. If those made here are approached, the pattern of cereal use will be much the same as it is at present. If the total production of corn is about the same as at present, 95 million tons, it will be more efficiently produced on fewer acres. Of this amount ten or even 15% may be devoted to industrial non-food uses as starch products. Other uses for dry milled products, spirits and seed will probably require the same amounts as at present. In the case of wheat, from 14 to as much as 20 million tons will be used for human food. The remainder of the wheat must compete with corn and oats for the feed market or with corn for the starch market until research develops a need for wheat gluten. Unless such a development occurs, the amount of wheat produced annually will probably be considerably decreased. The production and uses for oats will probably not change appreciably.

This over-simplified picture of the future utilization of cereals can be radically changed by advances in research in any of a number of fields. Basic discoveries in agronomy, mutants obtained by radiation, or more knowledge of the effects of diet on health and growth may alter the assumptions made here. The possibilities for greater industrial use resulting from fundamental advances in polymer and surface chemistry have been outlined as they might affect starch. Similar advances in protein and oil research could have equally beneficial increases for cereal consumption. The necessity for research on cereals and other agricultural products can be demonstrated in many ways. To the scientist, the lack of detailed information of the composition and physical properties of agricultural products and their derivatives is evidence of need for more research. To the layman, for an industry, research expenditures as percent of sales

are indicative of progress. Agriculture is lagging far behind other industries in research. A broker's letter on stocks states, "Generally the industries and companies which have made the greatest progress in recent years are those which have been most research-minded". This same letter cited twenty-four representative companies which spend from 2.4 to as high as 13.4 percent of sales on research. This is in contrast to the 0.5 percent of farmers' total sales spent on agricultural research. It is fair to conclude that research on cereals must be greatly expanded if their utilization is to have a promising future.

References

1. Agricultural Marketing Service, U. S. Department of Agriculture, Washington, D. C., Grain and Feed Statistics, Statistical Bulletin No. 159 Revised May, 1957.
2. Agricultural Marketing Service, U. S. Department of Agriculture, Washington, D. C., Agricultural Outlook Charts 1955, 39.
3. Daly, Rex F. The long-run demand for farm products. Agricultural Economics Research **8**(3): 73–91. 1956.
4. Woodworth, C. M., Leng, Earl R., and Jugenheimer, R. W. Fifty generations of selection for protein and oil in corn. Agronomy Journal **44**: 60–65. 1952.
5. Frey, Kenneth J., Brimhall, B., and Sprague, G. F. The effects of selection upon protein quality in the corn kernel. Agronomy Journal **41**: 399–403. 1949.
6. Report of the Task Group on Industrial Use of Grains (Other Than Alcohol) of the President's Bipartisan Commission for Increased Industrial Use of Agricultural Products, February, 1957.
7. Hosking, Floyd J. Enormous new corn markets are possible through multiplied research. Chemurgic Digest **16**(5), 4–6. 1957.

Utilization Abstract

Eucalyptus. The genus *Eucalyptus*, originally of Australia and adjacent islands, has been carried to 36 countries with warm temperate climates. There are 525 species named, and probably many more exist. These species, which make up 94% of Australian forests, have a wide range of variability in growth habits and morphology. Botanical classification is difficult, and very complete material is needed for adequate identification. *Eucalyptus* species vary in size from shrubs to giant trees; there are many different qualities in the wood, in hardness, in color, in grain and others.

There are as many variations in the utilization of Eucalypts as there are differences in form. The wood of jarrah (*Eucalyptus marginata*) is fire-resistant and is used to line chimneys in Western Australia. This species is also used where decay resistance is important: in wharf pilings, railroad ties, and for paving blocks. With these qualities is associated the characteristic of easy working for fine furniture. Frequently, eucalypts serve as wind-breaks, as ornamental shrubs and trees, as soil stabilizers, fuel, fence posts and mine timbers. Wood from *Eucalyptus cornuta*, "yate", of Western Australia was used by pioneers as cog-wheels in wind-driven flour mills. *E. regnans*, the giant gum or mountain ash, has very straight-grained wood. Trees of this species frequently grow to heights of 150 to 200 feet.

Eucalypts grow easily and fast in many countries. Brazil, with 900,000 acres, has the largest number of plantings, with the Union of South Africa, Madagascar, Spain and Portugal all having over 100,000 acres. (John Sidney. *Natural History 66*(7): *370–372. 1957*.)

The Production of Papain—*An Agricultural Industry for Tropical America*

In tropical America there is very little interest in the cultivation of Carica papaya *for the production of papain. This article, dealing primarily with field production and processing of crude papain, demonstrates that where coffee is grown commercially, papain may be produced profitably.*

S. BECKER [1]

Introduction

Carica papaya, commonly called "papaya" or "pawpaw", is indigenous to tropical America. Spanish and Portuguese sailors are said to have introduced seeds to other tropical countries, and today the papaya is well known as a relished article of food in all tropical lands. The fresh fruit is served in numerous ways: by itself; in a variety of combinations for salads; and frequently as a refreshing drink. Papaya is also preserved as a candy or confection, a paste, a puree or syrup, and a canned juice. The edible fruit pulp has a mild, pleasant flavor. It contains about 90% water, is rich in Vitamin A and also yields Vitamin C, carbohydrates and various minerals. It aids digestion and is said to be vermicidal to certain intestinal worms. The merits of the papaya fruit are indeed far too little known.

In addition, the papaya plant contains a milky latex which has in late years become a valuable commodity of commerce for its power to digest proteins. This sap, when dehydrated, is called "crude papain", and there is a steady, growing demand for it in industry. Although all parts of the plant contain latex, in commercial papain plantations only the green, immature fruits are used for latex extraction, because exudations from unripe fruits are much more vigorous than from any other part of the plant. Before 1936, the demand for papain was rather limited, Ceylon being almost the only producer.

In 1935 the author started a small, experimental papain plantation in Africa where, soon after, other progressive planters joined in establishing larger areas. Following Tanganyika and Uganda, production was also taken up in Kenya, South Africa and Queensland, Australia, and lately in the Belgian Congo. Today Africa is the chief producer with Ceylon next. However, production in Kenya and Queensland is of little consequence. In America, the original home of the papaya, very little interest was and is exhibited. The general opinion is that papain production does not pay because wages are too high. Agricultural wages, however, differ from one country to another, and in some of the Central American republics the factor of wages is certainly not discouraging. Where *Coffea arabica* is grown commercially, the wage level would also permit the production of papain, perhaps at a higher profit, as the costs for establishing and maintaining a coffee plantation are generally greater than that of a *Carica* plantation. As a basis for comparison, a latex tapper, at present prices, will gather in one shift a

[1] Tropical Horticulturist, P. O. Box 652, Beverly Hills, California.

FIG. 1. *Carica papaya* tree of sturdy, healthy growth in deep humus forest soil, 16 months old. Variety not prolific.

quantity of latex valued from $18.00 to $32.00, a performance which compares favorably with the value of coffee picked by a coffee picker in the same time.

Chemical Properties and Utilization

As this article primarily deals with field production and processing, only a few notes on the properties of papain are given. The milky latex, which is most abundant in green fruits, contains two enzymes called "papain" and "chymopapain". Both are active principles in breaking down or digesting proteins. The proteolytic power of these enzymes is considerable. Meat wrapped over night in crushed papaya leaves becomes more tender when it is cooked. A much stronger action will result if a tiny pinch of crude papain is put on chicken or any other meat. After roasting at ordinary oven temperatures, the meat will be completely digested where the papain was applied. Though the latex has a lesser enzyme concentration than the crude papain, certain precautions must be taken when working with it. Wiping one's perspiring face or skin with latex-soiled fingers causes an immediate burning sensation; latex in contact with a wound produces pain, and the tiniest droplet in one's eye gives severe irritation. The worker gathering latex in the plantation must wear rubber gloves; otherwise, the skin of his fingers and palms will be digested.

In laboratories, the imported crude papain is purified and the enzymes can be separated in their purest form, as crystals. The degree of proteolytic action is measurable: in the United States mostly by the milk-clotting method, while in Europe tests are chiefly carried out by comparing the weight of papain to its proteolytic power. Commercial crude papain of good quality has the capacity to digest 35 times its own weight of lean meat. There are a number of other methods in use. For the producer-planter it is important to know that the enzymes deteriorate in prolonged contact with oxygen, certain metals, and other oxygen-containing compounds. Oxidation lessens the proteolytic power and consequently the value of the papain. Faultless latex or crude papain should be ivory-white or yellowish-white. A pinkish, reddish or brownish color instead indicates progressive oxidation whereby the product is reduced to inferior grades, difficult to sell.

Papain is used extensively in the meat industry as a tenderizer. It is used in the textile industry for reducing shrinkage of certain types of wool, in the beer industry for clarifying beer and in the tanning industry for bating hides. Papain is an important ingredient in digestive medicines and is used in the treatment of various ailments. It finds various applications in pharmacy and cosmetics.

Environmental Requirements

Successful production of papain depends on certain fundamental requisites, among which the foremost are: experienced management, technical aptitude in latex extraction and processing, and high latex yield. Where the local subclimate offers the essential climate requisites for sturdy growth, the latex yield will reach a high level. Good cultivation methods will not only prolong the seasonal periods of latex collection but will increase the annual yield considerably. Latex can, of course, be collected from any tree or grove, but to make papain production a lucrative undertaking a high latex crop per tree is essential.

The following environmental conditions are considered ideal for papain production:

Temperatures. An average diurnal temperature range between 21° and 33° C. (shade temperature) is ideal for sturdy growth. Higher temperatures do no harm, provided the soil has ample moisture and the air is not too dry. Slightly lower than optimum temperatures have no bad effect, except a slowing down of

the physiological activity. If temperatures stay below 16° C. for extended periods, growth is apt to be arrested, with a corresponding low output of latex. Slight frost kills young trees.

Precipitation. Soil humidity on a fairly high level is most important, but the soil must not be wet. A minimum annual rainfall of 1200 mm. may suffice, provided proper cultural measures are taken to preserve soil moisture. However, where soil is stony or shallow, tending to lose its moisture rapidly, rainfall up to 2000 mm. annually may be necessary or irrigation has to be practiced. Rainfall should be well distributed over the entire growing season, if possible over eight months. If the soil becomes too dry, even for a short period, root activity will be arrested to such an extent that latex output will drop considerably.

Sunlight. Papaya plants require full sun; any shade falling on trees must be avoided.

Atmosphere. Under hot and dry environments apical growth is very slow, the internodes on the trunk are very short, and latex flow may be anything from poor to moderate. Fruits often are so densely set that they have insufficient room for lateral expansion and become seriously deformed as they mature. The other extreme represents frequent rainfall the year around, high relative humidity, and fairly high day and night temperatures. Here the apical growth is very rapid, the internodes become greatly elongated, and fruits are widely spaced. A young tree three meters tall may have only ten fruits, the latex pressure of which is high. Needless to say, both extreme conditions are not conducive to best latex yields. The optimum conditions of humidity lie somewhere between and consist of a regular rainy season lasting from six to eight months followed by weather with less or no rainfall.

Wind. While gentle winds are regarded

FIG. 2. 31-month-old stand of papaya with high yield of latex.

as beneficial, strong winds will increase transpiration excessively, particularly during hot, dry weather. Not only is latex pressure reduced considerably, but also a great deal of damage can be done to the brittle foliage. Windblown dust discolors the tapped latex and is responsible for many impurities. If dust is from lateritic soils, it gives the latex an undesirable reddish tint.

Altitude. It must not be assumed that the tropical lowlands, though producing the tastiest fruits, are always the most suitable for latex production. In many countries near the equator excellent environmental conditions may be found at altitudes of 800 or 1000 meters.

Soils. *Carica papaya* will grow to some extent in almost any kind of soil and may even produce tasty fruits on poor soils. For the purpose of abundant latex supply, however, the plants must have fertile soils with a high humus content. A slightly acid soil (pH 6 to 6.5) is desirable. Too sandy soils or heavy clays should be avoided, but porous young volcanic soils, light loams, sandy forest soils, or rich sandy alluvial sedimentary soils with high humus content are very suitable. Plant nutrients must be abundant and in available forms. Soil depth, although important from the point of nutrients and water reserves, need not be great, if the subsoil is of porous structure.

Drainage Topography. Papaya must have excellent drainage or it will not do well. The author has at one time grown very vigorous papaya trees on shallow, rocky, limestone topsoil of only 40 cm. depth under irrigation and heavy mulching, but the subsoil had excellent drainage. This, however, should be taken as an exception rather than a rule and shallow soils should be used only after extensive tests have shown their usefulness.

With regard to topography, any plantation should be laid out on fairly level ground or softly undulating hills. Steep hillsides must be avoided as the gradient interferes with all routine work, particularly the gathering of latex. Low depressions where water accumulates and stands after the rainy season are quite unsuitable for papaya plantations.

Plantation Management

The prospecting papain planter will be well advised to make test plantings on possible plantation sites. Utilizing the best cultural practices and running impartial tests for latex yield, although time-consuming, are very important in land selection.

Preparing the Land. Preparatory to planting, the land has to be cleared of all native vegetation. Ploughing will be beneficial, but is not a necessity. A certain amount of leveling is often required and grading must be done if furrow irrigation is to be used. The cleared area should be divided into square blocks of equal and convenient size, varying in size from one acre to one hectare. Each block will be treated as a separate, single unit in planting, tapping, cutting down, and replanting. They should be separated from adjoining blocks by a service road. Supervision and management are greatly facilitated by such divisions.

Raising Seedlings. About 6000 papaya seedlings with five to seven seedlings to each tree-spot are required to plant one acre. Approximatel y 550 shade-dried seeds will weigh one ounce. Three months before the intended planting time, seeds should be sown in open beds 90 cm. wide and three to six meters long, with comparatively wide service paths between each bed. No shade is required. The seed bed should be well cultivated, and a good supply of water must be near at hand.

Seeds may be planted in drills 14 cm. apart and covered with about 1 cm. of light soil. If there is no rain, daily watering with a sprinkler can is necessary. Germination takes place in three to four

weeks. Hand weeding must be done whenever weeds appear. When seedlings reach a height of 15 to 20 cm., they may be transplanted to the field. To harden the stems, while still in the seedbed, it is a good plan to cut the tops to a height of 10 cm. Seedlings may be cut several times to check their growth, if for any reason planting must be postponed.

Transplanting. In soils with a high humus content and a good structure, there is little need to dig plant-holes prior to planting. Where this is not the case, plant-holes of about 30 × 30 × 30 cm. ought to be made. To refill these at planting time, a mixture of top soil and forest humus, with a handful of bone meal, may be used. Rainy weather or late afternoon hours are best for transplanting. The seedlings removed from the bed are placed in a damp box which the worker carries. Five to seven seedlings are planted in each plant-spot. If the weather is dry, they must immediately be watered and shaded by sticking some branches or fern fronds around them. After one month or so they begin to make fast growth and should begin to bloom after five to seven months in the field.

In situ Planting. Seeds may be planted in the permanent setting. Here, the seeds, after having been soaked in water for a day, are planted 10 to 20 to each tree-spot. A short stick indicates their position and some shade must be provided. Close watch must be kept on the seeded spots. They must be kept free from weeds and the shading branches removed soon after germination.

Planting Distances. The diameter of the crown determines the spacing of the trees. With proper spacing, the crowns of adjacent trees will not touch. Very often a spacing of 210 cm. × 210 cm. (7 × 7 ft.) is adequate, but it can hardly be said that trees of this crown size are very vigorous. This planting distance gives 890 tree-spots to the acre or 2250 to the hectare. For most vigorous growth, trees should be spaced 240 × 240 cm. or even wider; in some cases plants are spaced 300 × 300 cm.

Sexual Forms. Only the female form is used for latex cropping in papain plantations. The male flowers are borne on long, drooping, flower stalks in great numbers, and the female flowers are produced on short, branched stalks in the leaf axils. Each stalk carries from one to five female flowers. As there are no means to determine the sex of a plant before it sets flowers, several plants are grown in each plant-spot.

Discarding Plants. On each plant-spot the first three trees which show female flowers are preserved and the rest are destroyed. About one month later the strongest of the remaining three females is preserved, and the other two are pulled out, leaving only one female to each plant-spot. It would be absolutely erroneous to leave more than one female for production in each spot. It is advisable to preserve from 10 to 25 males to each 1000 females, suitably spaced in the plantation, to be assured of good pollination and better-developed fruits.

Continuity of Latex Supply. Once a plantation is in production, continuity of latex supply becomes an essential factor. Although the period of good latex flow is rather short, it is not feasible to make a general prediction when a tree will become unproductive. However, within his own locality, the experienced planter is quite able to foretell the productive life-span of his trees. This varies considerably and may be anything from 28 to 48 or more months, but, as a rule, three-year-old trees set their fruits so high on the trunk that gathering the latex becomes increasingly difficult. This is the case when fruits are higher than 350 cm. above ground level. Furthermore, the size and the number of fruits, as well as the latex yield decrease with age and height of trees. In many plantations the

economic age limit is around two and a half years.

Latex yields are greatest in the first twelve months of tapping. In the second year, the yields are about 65% of the first year's diminishing more in each following year.

Two methods are available to insure constant production: rotation planting or by a second plantation.

Rotation Planting. Rotation planting is practiced where land is scarce or expensive. If the first set of trees becomes unproductive at the age of 28 months, eight months previous to the end of the productive period new seedling trees should be planted between the old trees as in Fig. 3. These seedlings will begin to yield latex eight to ten months later, at the time when the old trees are scrapped. Later, when the second set becomes exhausted, the same rotation planting is to be repeated, the third set of trees planted where the first set was planted. This practice may be repeated within the same unit of land until the soil shows signs of exhaustion.

FIG. 3. Rotation planting.

Second Plantation. Where land is abundant and cheap, one might plant another piece of land, timing the planting to begin yielding when the old plantation is exhausted. This operation can be continued on the same basis as rotation planting, taking care to have the new crop in production at exhaustion of the old.

Naturally, in any plantation, all the trees of one planting will not reach an unproductive stage in exactly the same month. With rotation planting particularly, it would be a bad practice to cut down the worst trees only and save the better ones. It is most important, therefore, that in the month of calculated exhaustion, all old trees be removed. This is necessary in order to bring up a subsequent set of trees uniformly.

Organic Manuring. For an abundant latex supply, the most vigorous growth must be induced. In most cases, a high level of soil fertility should be maintained by liberal manuring and other means which are economic and practical. Any bulky animal manure which is worth the cost of handling and transportation may be used with discrimination. Manufactured fish-, bone-, or bloodmeals are excellent, though often too high-priced. Any additional vegetable or animal material, if partly decomposed, is an excellent form of organic manure. Very fertile virgin soils may have no need for manuring for a number of years.

Mulching. Mulching induces a strong growth in papaya plants. A blanket of vegetative matter 15 to 25 cm. in thickness, spread over the entire surface, is extremely beneficial, especially under tropical conditions. As the layer of mulch decomposes, more should be added. The microbiological activities in the decomposing mulch are of the highest impor-

tance. With the exception of hard, woody materials, any vegetative matter may be used for mulching. In fact, mulching is so valuable that vegetative matter can be grown profitably for this purpose on adjoining lands, as is done in well-managed coffee plantations. Mixtures of materials should be given preference, as the use of one material (grass, for example) harbors the danger of fire during dry weather.

Mineral Fertilizers. In lands which have been cultivated for a number of years, latex yields will be considerably increased by using one or several types of inorganic fertilizer. The value of addition of any of the mineral fertilizers can be determined only by tests. *Carica papaya* is rather demanding of nitrogen. This nutrient is most appropriate when applied in frequent but small quantities in almost any older plantation.

Tillage. Given good edaphic conditions, papaya produces a number of surface roots. Tillage should, therefore, be restricted to occasional hand hoeing not deeper than two to three cm. Deeper cultivation injures too many of the shallow surface roots, and for this reason machine cultivation cannot be recommended. Light hoeing is generally done when a carpet of small weeds has to be destroyed or when the soil surface tends to become crusty.

Weeds. No tall weeds are tolerated. During the rains, weed growth should not be hoed, but repeatedly slashed off just above ground level. Where mulching is practiced, tall weeds penetrating the mulch must be pulled out by hand.

Intercropping. The planting of catch crops between the rows of papaya trees cannot be recommended. Under no circumstances should any crop be planted which necessitates digging ridges, trenches or large holes as with sweet potatoes, manioc, etc. Any catchcrop would seriously interfere with tapping operations. All the soil moisture and nutrients should be kept available for the papaya alone.

Irrigation. Irrigation should be regarded as a help in prolonged periods of dry weather to keep up the normal physiological activity of plant life but not as a means to force growth all year under climatic conditions which are too dry. Where irrigation is intended, the whole area must be graded previous to planting the first seedlings and the demarcation of the rows must be done in accordance with the fall of the lands. As a rule, it is not advisable to "sheet" irrigate the whole surface of the plantation. Feeding furrows about 20 cm. deep should be made, each of them running in the center between parallel rows of trees. Water led into those feeding furrows should run slowly; and while a little may be allowed to overflow here and there, the whole soil surface must not be inundated. It is important to keep the area around each papaya stem dry. How often these feeding furrows are to be filled depends entirely on circumstances (soil structure, temperature, wind, angle of decline, condition of trees, duration of dry weather). No rule can be given and experience is the only way to tell.

Seed Supply. Size and shape of fruits, vigor of vegetative growth, high latex yield, and early fruitsetting are points to bear in mind when selecting mother trees for seed supply. Seeds taken from selected mother trees produce plants most of which have the characteristics of the mother tree. For latex production, a long to oblong-shaped fruit, weighing from 800 to 1800 gr., is most suitable. These offer a larger surface for latex extraction than other types. Plants producing globe-shaped fruits or numerous small ones or of a sexual type not freely pollinated are inferior for latex production.

Diseases. Most of the diseases of papaya can either be kept in check or completely controlled. Reliable information

is available from literature and bulletins or pamphlets issued by various agricultural departments. One of these, for example, is Circ. 136. 1955, of the Agricultural Extension Service, Gainesville, Florida, which gives directions for the control of the papaya fruit fly and other insects prevalent in Florida and the West Indies.

There is, however, a mosaic disease which can become very destructive since proper control measures have not yet been worked out. Types of this disease have been reported from East India, the Philippines, Hawaii, Florida, Australia, the West Indies and lately, Africa. The symptoms, as well as the destructive power of the different types of mosaic disease, vary to some extent. Judging from the description of the African and Hawaiian forms, the actual damage is comparatively slight. A rather destructive form occurs in Haiti. There, the first symptoms are the appearance of watery, green, sunken, irregular spots from one to four mm. in extent near the apex of the trunk. Soon after, the youngest, terminal leaves lose their healthy color, become mottled, pale yellow-green and die off within a short time. Then the whole apex dies, followed by the older leaves and finally by the trunk itself. As a rule, young, bearing trees are killed to the ground. The lower part of the trunk of older trees sometimes survives. Later, new growth may sprout from the trunk of these older trees; and this, in turn, becomes diseased. In the early stages of the infection, sap pressure decreases first in the youngest, green fruits, their growth is arrested and they fall from the tree. The same happens with older fruits later and thus, within a few weeks or months, a whole plantation of bearing trees may be destroyed. Trees are most susceptible when they have a big crop of fruits. Although the first (lowest) fruits of a newly infected tree may be tapped successfully for a short period, soon all will become useless for tapping. It is very probable that different strains of viruses and different environmental conditions cause the variability in this disease.

The author, who is familiar with the West Indian form, has not observed this type of mosaic in Brazil, Hawaii, and Africa. In areas where the occurrence of mosaic is possible the plantation must be checked frequently, and diseased trees must be removed as soon as they show symptoms of attack. No papaya plantings should be established in localities where severe forms of mosaic occur.

Disposal of Fruits and Trees. There will be a great quantity of scarred, yellow, mature fruits. These are satisfactory for human consumption, and the author has sold truck loads of them on the Brazilian fruit market. Their juice, too, may be used for fresh drinks. Those which cannot be sold may be fed to pigs or may be buried in shallow holes as far away from the remaining plants as possible. They may be cut into small pieces and left to dry, covered with a little soil. The whole fruits should not be left on the surface to become a rotten, mouldy mass. Felled trunks should be chopped into small pieces and the chips lightly covered with soil.

Collecting the Latex

Time of Collection. Gathering the latex should be done during the morning hours or on misty, cloudy days or after a good rain, generally in seasonal periods when warm temperatures and humid conditions coincide. The observation of these is conducive to considerably higher yields. Gathering latex from the trees during times of hot, dry, and/or windy weather conditions would not only be a wasted effort, but would considerably weaken the whole stand of trees. Tapping is also unadvisable at low temperatures.

Fruits to be Tapped. The oldest fruits (lowest on the trunk) alone should be tapped while they are still entirely green. For various reasons it is unadvisable to

extract latex from all the green fruits on the trunk. Fruits that have nearly reached their full size but are still green give the highest latex yield. If the younger, small fruits higher on the trunk are tapped at the same time as the old fruits, growth will be arrested and they will ripen prematurely. The whole tree will be greatly weakened by the repeated, excessive loss of fluid. When a fruit, irrespective of its size, develops yellow patches on its skin, its sap pressure, its latex quantity, and the enzyme concentration diminishes rapidly. A fully yellow fruit contains little latex and almost no enzymes.

Tools for Tapping. A gang of tappers, consisting of two workers, must be supplied with one incisor, two latex trays, one wooden scraper, two collecting boxes, two pairs of rubber gloves, one pair of sunglasses, a soft brush, a bucket, and a soft sponge.

The incisor, used for making the incisions in the skin of the fruits, simply consists of a stick or stake to which part of a common, double-edge safety razor blade is attached. The blade is inserted in a stake of light, tough, well-planed wood eight to ten mm. wide and thick enough to be stable. The length depends upon the height of the fruit. No more than three mm. of blade should be exposed, the sharp edge pointing backward. If the stick is taken from suitable wood, it will hold the blade firmly. If not, the blade may be cemented into the slit by using a waterproof household cement, or by tying thin silk or nylon thread around the stake near the blade. Any sharp edges on the head of the stake should be rounded off.

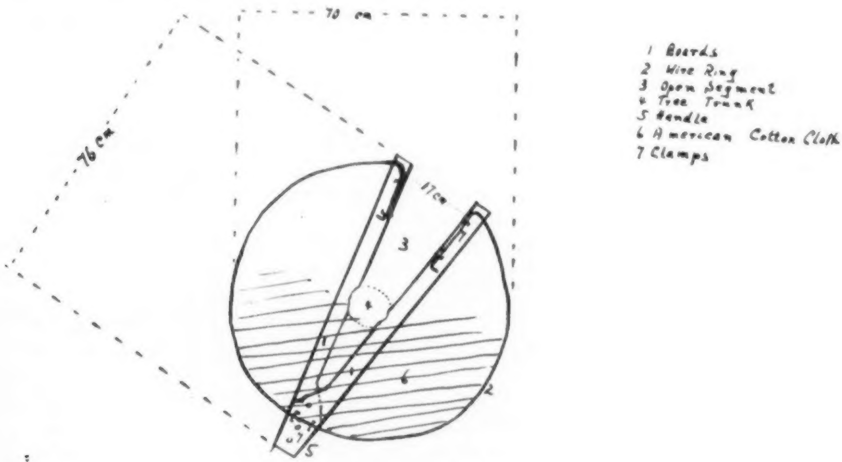

FIG. 4. Dimensions of latex tray.

At least two sizes of collecting trays should be available, one to fit trees with trunk diameters from eight to ten cm., the other for diameters greater than this. Details for assembly of the trays are shown in the accompanying sketch (Fig. 4). The jaws (boards) of the supporting frame are made from light, tough wood 76 × 8 × 1 cm., tightly screwed together at one end (scissors fashion) to allow for an opening of 17 to 18 cm. for the smaller tray, 22 or more cm. for the larger. To these supporting frames a 3-mm. diameter galvanized wire ring is at-

tached in a manner to leave the jaw segment open. A good grade cotton cloth is sewed to the wire ring, again leaving the jaw segment open. The cloth should not be too taut. In order to support the frame in position on the trunk, a stout rubber band is fastened on the lower side of one frame, drawn tight around the tree, and fastened to the opposite framing member. To give the tray stability on the trunk, two hinged legs of light, durable wood are attached on the under side of the framing members. These are pointed on the lower end to secure them when the tray is placed on the trunk. This design is light, easy to set up, to transport, and to clean. The author, having tried many other designs, prefers this type to any other.

A shallow, wooden spoon is used as a scraper to transfer the coagulated latex from the collecting tray to the collecting box. The box should have no metal parts exposed and must be made from a wood which has no pigmentation. A convenient size is from two to three gallons. An enamelled bucket may be used as well.

Tapping Operation. The successful operation of a papain plantation depends largely upon efficient tapping. Too often indiscriminate tapping with too many or too deep cuts or using all green fruits is practised. If small fruits are tapped, there is very little increase in size, and they soon become totally unproductive. Trees receive a severe shock when all fruits are tapped simultaneously, and even the largest fruits do not produce well. There will be no latex flow, only some dripping. Most of the latex then sticks to the fruits and dries in a brown hard crust, a great nuisance for subsequent tappings. Such practices mean serious loss per tree per acre.

A helper should precede the tapper the day before, trimming, cleaning the trees, removing old stumps, and cutting tall weeds to pave the way for the tapper. Removal of a number of large leaves from each tree must be prevented, however, as the reduction of photosynthetic areas will decrease the total latex output considerably.

The number of fruits ready for tapping may vary from six to ten or more, and the number selected for stage tapping is arbitrary. However, any fruits above this stage must not be touched. When, after repeated tappings, the lowest section of fruits develops yellow patches or the latex yield decreases, all fruits of this section are removed from the tree. Fig. 5 shows tapping in sections. A fruit section will be tapped repeatedly, at intervals from five to eight days, until latex flow diminishes to an extent which justifies the removal of this stage from the tree.

The tapping operator fixes his tray by simply pushing the open segment against the trunk 40 to 60 cm. below the lowest fruits, tightens the rubber ribbon underneath the tray around the trunk and puts the bracing legs into position. A piece of banana leaf is placed over the open jaw-segment. This operation takes no more than ten to fifteen seconds. The moment the tray is in position he makes incisions in the skin of the lowest section of fruits, also a matter of seconds. When dripping has ceased, he moves his tray to the next tree. A deft tapper may work with two or three trays at a time, thereby increasing his performance very considerably. At this rate, he will average thirty or more trees per hour.

All incisions must be made vertically, thus insuring the maximum quantity of latex dropping to the tray. No more than four incisions at one time should be made on large fruits, and smaller ones should have fewer. Any greater number of incisions on a fruit will, contrary to common belief, result in a lesser quantity being collected, as much of the latex remains in droplets on the fruits. Frequently, tappers make many incisions, literally covering the skin with a net-

work of cuts and scratches. This practice produces a much lower latex output.

As mentioned already, incisions must be very shallow, a depth of 2 mm. being ample. Deep incisions often do not heal over, and frequently fruit-rot occurs. Whenever a quantity of latex has accumulated on the tray, the tapper must scrape it into the collecting box, using the wooden scraper, picking out foreign materials which have accidentally fallen on to the tray.

rubber-gloved fingers or a very soft brush he wipes this latex into a cup and empties it into his own collecting box. If carefully collected, this latex may also be used for A grade. The helper's last operation is to give each wiped fruit a few strokes with a moistened sponge to remove the remaining film of latex. This will greatly facilitate the next week's tapping of the same fruit.

After the tapper has delivered his shift's collection, the tools must be

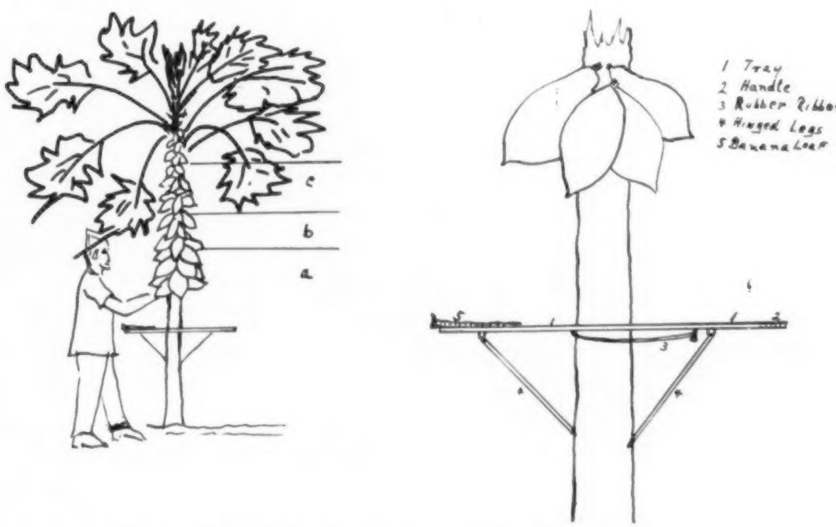

FIG. 5. (Left) Tapping in stages or sections. (Right) Tray in position.

washed in clear water. The tray must be scrubbed with a hard brush, rinsed and hung up for drying. Cleanliness exercised in all the tapping operations is of utmost importance, and all foreign matter must be kept out of the latex.

At the moment the incisions are made, the latex should stream from the fruit. The rate of flow quickly diminishes from a steady stream to dripping. It is not required that the tapper wait for the very last drop to fall. Usually he removes his tray when dripping becomes very scarce.

The helper follows the tapper fifteen minutes after the tapping operation to wipe off the wax-like coagulated latex which oozed from the incisions after the tapper has removed his tray. Using his

Processing the Latex

For the purpose of preserving the proteolytic action of the enzyme, the freshly tapped latex must be processed without delay after it has been delivered by the tapper.

Processing may be accomplished by salting or dehydrating the latex. The former process, not observed by the author, involves a partial dehydration to a paste-like consistency and the addition of common salt (sodium chloride). It is claimed that by this technique the proteolytic enzyme activity may be maintained unreduced for several months. The dehydration process, however, is the main subject in this paper.

In the early days, latex was simply sun-dried, a primitive, inefficient technique, giving a low-quality product. For modern, commercial production, a kiln or oven which can be operated in any weather condition is essential. If the oven is well-constructed and skillfully operated, the highest quality of papain can be made, providing, of course, that the gathered latex is pure and faultless. Many different types of plantation-built ovens are in use, varying in details of design and construction.

Oven Requirements. The available source of heat determines the type of oven to be constructed. Under rural, tropical conditions, electric or oil heat is probably too expensive to consider. Wood fuel, however, is usually abundant, and the following description gives details for an oven utilizing such fuel. The chief requirements are: simple construction, inexpensive materials, economic operation, and efficiency in performance.

Horizontal Oven. The main parts of this oven are: separate furnace or fire chamber, a horizontal heating canal with chimney, two interior walls serving as the support for the drying frames, and a shed-like building enclosing the entire drying chamber (Fig. 6 & 8). Though not necessary, the piece of land selected for the construction should have a slight rise of 1 : 10. The furnace is built from bricks or cement blocks, utilizing old auto or truck springs as support for a ceiling of layered earth. Dimensions given in Fig. 7 are interior measurements. To give the attendant ample working room and to provide adequate airdraft, sufficient earth has to be removed in front of the stokehole.

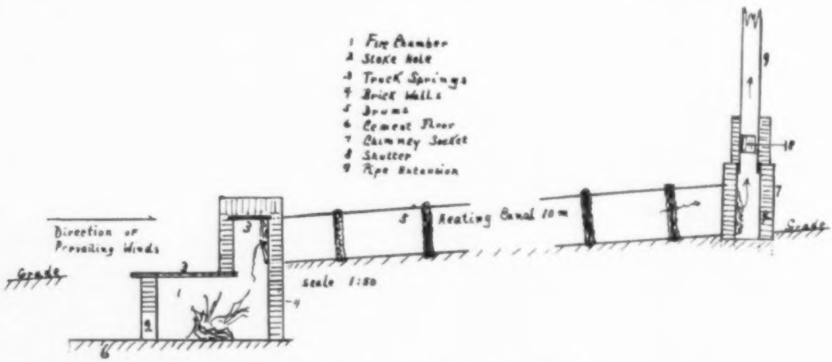

Fig. 6. Side view of heating structure.

Old oil, carbide, or bitumen drums with the tops and bottoms removed are satisfactory for the heating canal. The drums are laid in a straight line and secured with large stones on either side. All joints must be made tight by pouring a sand-cement mixture over them to prevent smoke from escaping. At the upper end, a chimney socket, built from bricks or cement blocks, supports a pipe extension of convenient length to increase

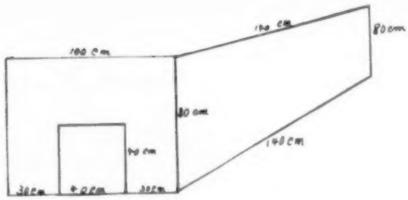

FIG. 7. Interior measurements of firechamber.

the draft. The chimney should be well anchored. To control the heat, a damper should be built into the lower part of the chimney (Fig. 6).

A protecting shed with a tight-fitting roof and doors to serve as a protection against adverse weather conditions is necessary (Figs. 8 & 9). Air must not enter the drying room through the roof or doors. The shed should not enclose the fire chamber and chimney. Where bricks are not easily obtainable or are expensive, the walls of the shed may be built of sun-dried bricks or similar local material. The interior walls should be smoothly plastered. To reduce dust to a minimum, the working floor should be covered with a ten cm. layer of pebbles. As roofing material, corrugated iron or asphalt paper laid on chicken wire serves well, but palm leaves, thatch or similar material should be avoided as spider webs, insects and dust will lodge in these and such impurities may fall into the drying frames below.

Adequate provision for ventilation is important. For incoming dry air, open vents must be made a little above the floor level in the shed walls, and for outgoing damp air, open vents must also be made in the shed wall underneath the eaves. Five bottom vents and ten top vents for each long wall ought to be sufficient. These are controlled by wooden props, or better, by means of cotton rags. Whenever there is need for increased ventilation, more vents are opened.

Speeding up the actual drying time, a matter of considerable importance, may be accomplished by installing a rotating ventilator which simultaneously expells damp, interior air and sucks in dry, outside air. Thus, a constant stream of air can be maintained while the oven is in operation. Such a ventilator might be driven by electricity, or by a small kerosene engine, and should be installed near the roof-line in the wall facing the chimney. If a rotating ventilator is used, air-vents should not be built into the long walls. Instead, two vents, each 10×20 cm., should be made in the wall facing the fire chamber, a little above the floor level.

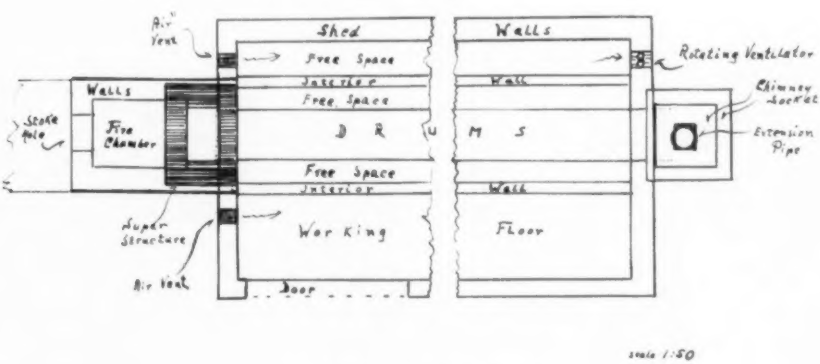

FIG. 8. Ground plan of oven.

Control of the fire is produced by a damper in front of the stokehole. The damper in the chimney also helps in controlling the draft.

The supporting structure for the drying frames simply consists of two low walls (about 90 cm. high) built parallel to the row of heating drums. Just above the floor, these walls, too, should be provided with small vents (10 × 10 cm.) 100 cm. apart to create an up-draft of hot air. Dimensions for these walls are given in the accompanying Fig. 9.

Drying Trays. Latex-drying trays should be 120 cm. long, 60 cm. wide, and 5 cm. deep. The corners are reinforced by triangular, light sheet metal. Over this frame good quality cotton is fastened by nails along the edges of the frames. Each of these frames will hold approximately 1500 gr. fresh latex and will be placed on the low walls above the drums. With a heating canal 10 m. long, there will be enough room for fifteen frames.

The capacity of this oven may be increased by arranging a whole set of frames vertically, as in Fig. 9. Space between the tiers should be at least forty cm.

Oven Operation. The operator has to make a fairly strong fire to heat the entire canal. After a stable fire has been produced, it must be regulated to produce an average temperature of 55° C. over the whole range. Short periods at 60° C. may not damage the products, but all effort must be made to maintain the optimum temperature of 55° C.

Coagulated latex must not be placed in the trays in uneven lumps nor smeared on the cloth. In order to produce an homogenous condition, a hand-operated aluminum fruit press may be employed. The coagulated latex emerges from the press directly onto the trays in a loose, thread-like mass. The press facilitates more rapid drying and at the same time reduces the impurities.

The filled trays are placed on the drying racks and kept there until the latex breaks and crumbles easily in the finger tips. If optimum conditions in the drying process have been maintained, the process should be completed in something less than twenty hours. There must be no interruption.

Latex gathered under optimum conditions contains from one part crude pa-

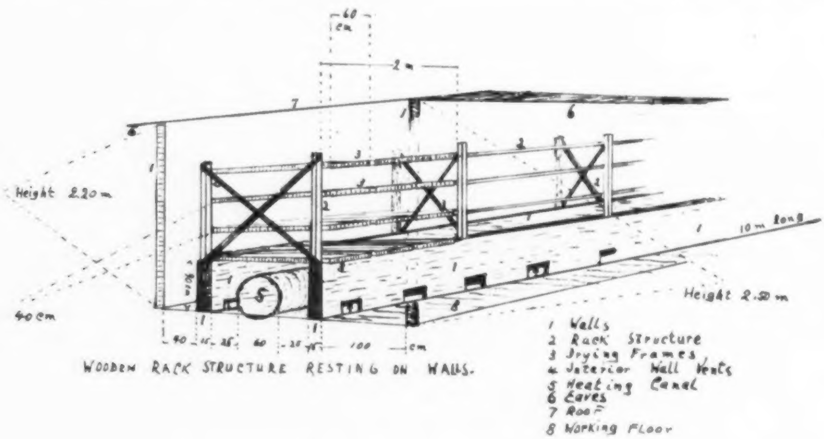

FIG. 9. Interior of shed.

pain to five or six parts of water, or 1 kg. latex yields 200 g. crude papain. This ratio may be changed by unfavorable conditions to one in ten. The crude papain, after the drying process, should have approximately nine to ten percent moisture content, with a consistency of brittle bread crumbs of ivory white to yellowish color.

For export, crude papain is generally ground into a coarse, granular form. It is very hygroscopic and must be filled into airtight containers as soon as it leaves the oven. Exposure to air or corrosive metals makes it oxidize, resulting in a loss of enzyme activity and a brownish-red discoloration. Crude papain is packed into new four-gallon gasoline cans for export. These are lined with a grease-proof paper, and the air is removed by a hand pump after being filled. These cans should be stored in a reasonably cool room. Packing crude papain in glass jars may be considered superior, providing they are packed in such a way as to prevent possible breakage during shipping.

Economics and Miscellaneous Information

Circumstances under which plantations are established and managed vary a great deal. Altitude, latitude, soil, climate, management, wages, worker's skill and other factors differ from one country to another, exercising their influence. It is therefore not feasible to give concrete figures which could be taken at their face value as a guide for any plantation. There are, however, performances which ought to be achieved whenever conditions can be described as suitable or good, and for these instances some figures are given.

The value of papain production to the economy of a country may be estimated from figures published by the Tanganyika Department of Agriculture where this industry is only a few years old. There, in 1947 the production of papain exported was valued at 306,485 English pounds, at that time equivalent to approximately $1.2 million. It is also stated that Uganda (East Africa) produced a crop of 50,000 kilos in 1949 and that Ceylon some years earlier had annual crops of about 100,000 kilos. Indian production, however, dropped because the quality sometimes did not conform to the standard requirements for importation into the U.S.A.

Wages and Economy. In general, it might be pointed out that in the absence of practical experience it is more advisable, even where extensive lands are cheaply available, to plant a moderate acreage and give the plants the very best cultural treatment than to plant a large area and hope for good yields. It is better to work with a smaller number of workers who are well-trained and better-paid than with many lower-paid common workers. As a rule, a plantation of moderate size under best conditions worked intensively will, in comparison, show a greater return than a large plantation worked extensively. Quite apart from the establishment of individual plantations, there are ways for the small papaya grove owner to profit from its production by delivering his latex to a central oven station on a co-operative basis.

Expenses in Establishing the Plantation. The chief item in costs is undoubtedly the clearing of new forest lands, if such are used. However, in many cases, grass- or bushlands that have been under cultivation of other crops are suitable. Thousands of seedlings are raised without much effort and expense, and one worker is able to plant one hectare (about 1800 trees) within ten days, provided the necessary preparatory work has been done. Maintenance, from setting out the seedlings until they come into bearing, chiefly consists of weed control and, as one worker may hoe from

700 to 1200 square meters per shift, about ten days are required for hoeing one hectare. The biggest cost item is likely to be the mulching and manuring. Provision for irrigation and regular watering routines will add to the costs. Planting, raising and weeding will amount to about 65 work days per hectare until the trees become ready for tapping.

Expenses for Equipment. With improvization, utilizing available materials, the author has built ovens costing less than $240. Much depends on one's ingenuity in using materials obtainable under rural tropical conditions.

Latex Yield and Personnel Performance. Given good management and optimum cultivation, latex yields should be nearly constant throughout the producing season. If these conditions prevail, a well-trained tapper, working at the rate of 30 to 40 trees per hour with two or three latex trays, should collect from six to eleven kg. of latex per shift. His assistant, wiping latex from the fruits, will increase this yield considerably. Approximately 120 shifts for tapper and assistant are required per hectare (ca. 1800 trees) per season. These figures are from the author's experience, given to present a rough idea of yield which can be expected.

Reports from available literature are quite variable. In most cases, it is not known whether the yield reports are from trees given specific care for crude papain production or from trees under random growing conditions. One report from South Africa gives a range of variation in production from 20 to 250 grams crude papain per tree per annum. This is of little practical value. From Tanganyika, various figures are given. One 25 acre plantation gave 4500 pounds, or 180 pounds per acre of crude papain in the first year. Another from Tanganyika reports from 60 to 100 pounds per acre per annum. In Peradenyia (Ceylon) trees spaced 10 × 10 ft., tapped every fourth day, gave an average annual yield of 11½ ounces (330 grams) of crude papain per tree, or 312 pounds per acre per annum. The author's own plantations, planted under ideal soil and climate conditions, produced average yields of 245 kg. crude papain per hectare the first season.

Prices. Prices for crude papain, grade A1, quoted in the United States by the Oil, Paint and Drug Reporter during the first quarter of 1957 were from $3.00 to $4.00 per pound. July to November quotations were from $8.00 to $8.50 per pound. Like other tropical commodities, market prices for crude papain fluctuate, but if one reviews the price levels for the past years, a steady increase may be seen. As the utilization of papain in industry becomes more firmly established, it is reasonable to believe that there will be a continued rise of prices.

In 1929, at a time when Ceylon was the chief producer, London prices were in the neighborhood of six shillings per pound. During World War II, prices registered a sharp rise, and African crude papain sold for thirty shillings per pound in 1947. At the present rate of exchange, the August-November quotations of $8.00 per pound correspond to sixty shillings. Annual imports to the United States amount to approximately one million dollars. According to the Commodity Reporter FT 110, of the U. S. Census Bureau, the quantity imported in 1956 was 246,022 pounds.

Selected References

1. Balls, A. K. Protein-digesting enzymes of papaya and pineapple. U.S.D.A. Circ. 631. 1941.
2. Macmillan, H. F. Tropical planting and gardening. 1935.
3. Papain production. Dept. Agr., Peradeniya, Ceylon. Circ. 22.

4. The Pawpaw. Extract from the Queensland Agric. J. Queensland Dept. Agr. and Stock. 1954.
5. The Pawpaw. Tanganyika Dept. Agr. Pamph. No. 52. 1953.
6. Papaya growing in Florida. Fla. Agr. Ext. Serv. Circ. 133. 1955.
7. Papaya insect control. Coop. Ext. Work in Agr. and Home Econ. Fla. Agr. Ext. Serv. Circ. 136. 1955.
8. Schwimmer, Sigmund. Industrial production and utilization of enzymes from flowering plants. Econ. Bot. **8**(2): 99–113. 1954.

Utilization Abstract

Agricultural Imports. Many imported agricultural products do not show up in trade statistics. Though of minor significance in our total economy, they are important dollar-producing exports from the countries involved.

The following spices are imported at the rate of 159 million pounds per year, valued at $29 million: pepper, ginger root, cardamon seed, nutmeg, mace, vanilla, cloves and clove oil, capsicum (cayenne) peppers, mustard, paprika, allspice, cinnamon, sage, caraway seed and others.

Many essential oils add fragrance in perfumes, soap and food, and several act as insect repellants. The oil of bergamot (from the rind of *Citrus aurantium* ssp. *bergamia*) is supplied entirely from the Calabria district of southern Italy. 117,000 pounds were imported in 1957. Other important essential oils for fragrance are lavender from France and Spain; geranium oil from France, Algeria and Madagascar; and lignaloe (bois de rose) from Brazil and Peru. Citronella and patchouli are important insect repellants, the former from Guatemala, Ceylon, Indonesia and Taiwan, the latter imported largely from Indonesia.

All essential oil imports are worth $22.3 million.

6.2 million pounds of pyrethrum flowers from British East Africa and 28 million pounds of cube root from Peru (for rotenone) were imported in 1957 for insecticides.

Important plant products for the pharmaceutical industry are valued at $5.3 million in 1957. Among these, the most significant are: quinine, ergot, crude opium, licorice root and extract, senna leaves, psyllium seed, belladonna, ginseng and stramonium.

Fibers of various sorts are imported. Those of vegetable origin include fibers from abaca, sisal, ixtle and henequen.

Latex, other than Brazilian rubber, such as gutta percha (from *Palaquium gutta*) and geluton or pontianak (*Dyera costulata*) have specific properties of importance to industry. Gutta percha is valuable for electric insulation, golf ball covers, dental plates and galoshes.

Cassava and sago starch from the Malayan peninsula, India and Indonesia have significant properties for food and industry.

Waxes from Brazil (from carnauba palms), and a variety of seed oils earn dollars for the countries of production. (Anon. *Foreign Agriculture 21(12): 14–17. 1957.*)

Technical Developments in Natural Rubber Production

The continuing importance of natural rubber is shown by the fact that 600,000 long tons are imported into the United States annually. Considerable increases in yield resulted from direct field experiments, and additional increases may be expected from studies in the laboratories of the United States Rubber Company.

C. E. RHINES

United States Rubber Company Research Center, Wayne, New Jersey

Rubber is one of the world's important crops, with 10,000,000 acres under cultivation. The cooperative selection program carried on by the world's rubber-producing countries for developing high-yield clones has constituted one of history's largest international cooperative endeavors. The many technical developments incorporated into modern plantation practices make successful rubber-growing one of the most complex of agricultural endeavors and sets it aside as a development most deeply indebted to the botanical sciences (1). Recognition was given to the continuing importance of natural rubber development at the recently completed modern Research Center of the United States Rubber Company at Wayne, N. J. In order to study the mineral nutrition of the natural rubber tree, *Hevea brasiliensis*, and to investigate other means of improving the growth, health and yield of this remarkable plant species, a greenhouse was included at the Research Center along with a 2,000,000-volt Van de Graaff accelerator and other ultra-modern laboratory equipment.

Investigations of rubber culture have led to over ten-fold yield increases from the earliest plantation date to present time and continue to promise further benefit. The new greenhouse at the Research Center operates directly in support of the Company's plantations in Indonesia and Malaya. These plantations, with 87,000 acres actually planted, were established in 1910 and are still operating, with great success. The plantation venture was undertaken as a mechanism of protecting the Company's raw materials position.

The natural occurrence of rubber in plants made possible man's venture into rubber technology. An abundant development of rubber in *Hevea brasiliensis* was a particularly important factor in the initiation of technical development. This tree is the original source of rubber and has remained the only plant capable of supplying rubber abundantly enough to support the world's growing demand. Strangely enough, rubber, which serves man so well, has no definitely known function in plants.

Rubber is present in many plants in as high or higher levels than in *Hevea brasiliensis*, but no other plant has made its supply sufficiently available to man to be of benefit to civilization. *Hevea* rubber comes from the latex vessel system just under the outer bark. The tree can be effectively tapped by the shallow, diagonal cut devised by H. N. Ridley, Plant Scientist working in Malaya at the beginning of the century. Skillful

FIG. 1. Two to four hours after tapping a tree, the liquid rubber is collected. The collecting buckets are empty kerosene tins. United States Rubber Co. plantation in Malaya.

tapping leaves the cambium layer uninjured so that bark regenerates for future tapping. Tapping can be progressively repeated down the trunk on alternate days in ½ circumference panels, without yield depression or tree damage. There is actually a tapping response, or increase in yield, after a brief period of tapping.

The rubber obtained from the tree is of such high quality and purity that simple drying or acid coagulation and pressing and drying of the latex produces a product completely acceptable for the majority of rubber items produced today. The crude plantation product, in the compound form produced by nature, is of such quality that rubber manufacturers demand it in an unmodified form. Chemical modifications are inferior for general use, even though great efforts have been expended in this age of chemical miracles to bring about improvements.

Primitive Indians of tropical America were the first rubber technologists. These people observed that a milky juice oozed when a rubber tree was slashed. They further observed that this dried into an unusual, tough, resilient product. They learned that the drying milk could be formed into balls that bounced in a lively manner and learned that these balls were useful in sport. They learned to dip forms in the milky fluid and dry them into useful products, such as footwear and bottles. They made these advances with the latex of *H. brasiliensis* which lends itself with ease to simple processing. They disclosed their products to early traders, who carried their rubber products to the rest of the world.

Rubber is well known to all as a major component of tires, rubber footwear and rain gear. The rubber industry comprises much more than this and is an integral part of the mechanical age, an age that could not have developed without rubber. Rubber goods production has reached the colossal sales level of $5,250,000,000 annually in the United States. Industrial goods alone reach a $1,200,000,000 level. Major industrial items are hose, fuel cells, hard rubber items, belts, foam sponge, mats, packings and tank linings. A huge industry is based on rubber milk, or liquid latex. Tires lead all rubber products in value and volume with 110,000,000 units annually.

The rubber industry was based entirely on natural rubber for over a century. A host of synthetic products now share the raw materials market with natural rubber. These synthetic newcomers were inspired by natural rubber because man would not have developed the need for them without the contribution of natural rubber. Synthetic products supply 65% of United States consumption and 35% of world consumption. Natural rubber production has stabilized at 1,900,000 long tons per year. By 1960, synthetic rubber production will be slightly above natural rubber production, and at a moderately stable level. Most products can be made from either natural rubber or several of the synthetic types; progressive manufacturers select the raw product most suitable for the manufactured item. Natural rubber continues unchallenged in many uses, particularly in large truck and bus tires.

A study of agricultural methods was undertaken immediately after initiation of the plantations. Tremendous benefits have accrued from resultant technical developments. Early plantation yields were about 300 pounds per acre at peak years; but cultural advances, improved fertilizer practices, and the selection of improved planting materials have advanced peak yields to about 2,000 pounds per acre per year for new planting operations. Developments in progress promise to bring peak yields to possibly 3,000 pounds per acre in the near future. Peak yields occur at 12 to 15 years of age. A tree starts bearing at five to seven years of age and is usually replaced with younger and more productive stock at 25 years of age.

Early experiments at the United States Rubber Company plantations demonstrated that nitrogenous fertilizers would give large growth and yield improvements (2). The publication of this work led to the use of nitrogen treatments on progressive plantations. Most other fertilizers were ineffective in early studies.

FIG. 2. Dr. C. E. Rhines examines twin rubber trees originating from split seedling.

Continued use of nitrogen on plantations led to a condition where nitrogen commonly failed to bring about normal response in recent check experiments. Continued use of nitrogen has thus produced the normal effect of severely depleting other elements. Simultaneously, mineral nutrition studies at the United States Rubber Company greenhouse have revealed (3) that the Hevea tree, like most plants, requires a complete nutrient supply for optimum development. Nitrogen, phosphate, potassium and magnesium are required at relatively high levels while calcium and sulfur suffice at very low levels.

A very high level of iron and a moderate level of manganese is required for vigorous growth and deep green color development. The other minor elements, zinc, boron, copper and molybdenum, are essential but only at very low levels and do not appear to impose serious deficiency threats. The high iron and manganese requirements are accompanied by a high soil acidity demand. Chlorosis develops on soils above pH 5.5, and this chlorosis is primarily due to immobilization of iron. Recent experiments at the new greenhouse have demonstrated that organic chelating agents are effective for imparting normal growth and appearance at unfavorable pH levels and for improving growth at optimum pH conditions. These agents are undergoing further tests as aids to rubber culture.

FIG. 3. Nutrient solutions are maintained in neoprene-coated containers to prevent growth of algae in the solutions.

Analytical work (3, 5) has indicated

that the cation contents of rubber leaves are useful indicators of soil fertility. Field studies carried out in conjunction with Research Center studies have revealed that serious potassium shortage is shown by a leaf content of less than 1% potassium (1% K). Magnesium deficiency is indicated below 0.2% Mg. High fertility levels of magnesium or calcium depress potassium uptake, while high levels of potassium and calcium depress magnesium uptake, and finally, high levels of magnesium and potassium reduce calcium uptake. It is important to maintain fertility conditions that assure adequate potassium and magnesium in the tree.

Other research activities promise much benefit to rubber culture. Improvements in Marcotting technics have been made. Progressive estates bud-graft high-yielding clones on seedling stock. The stock is known to affect yield, and select seedlings are utilized. Development of a practical vegetative rooting procedure is certain to lead quickly to yield improvement through supplying better stocks. Root diseases are the most serious of maladies at the major rubber-growing areas, and development of cuttings would accelerate selection of resistant stock. Hormones have been tested extensively for possible growth promotion effects, and preliminary evaluation is given to new pesticides.

A very important and very unusual application of plant hormones has developed in natural rubber production. Early indications of stimulation of latex flow were reported (4) at the Rubber Research Institute of Malaya. This has been developed to the position where progressive estates are applying a 1% to 2% solution of 2,4-D just below the tapping cut, on scraped bark, 2 or 3 times a year. A yield increase of 20% to 30% normally results, without damage to the trees. Many irritating and toxic substances produce similar effects, but

FIG. 4. Rubber seeds are shipped from Malaya in moist charcoal, by air express, to greenhouse in New Jersey.

the cause of increased latex flow has not been explained. Methods of investigation with isotopically-tagged 2,4-D are currently being developed at the new greenhouse.

An extensive study of the uptake of isotopically-tagged nutrient elements from nutrient solutions and the distribution of these isotopes in the plant is being undertaken at present. An investigation is also being initiated on the uptake of these isotopes from soil colloids shipped from rubber plantations. Comparisons of nutrient solution data and soil colloid data will determine the importance of fixation of nutrient elements by the soil colloids. The final phase of this project, after experimental techniques have been well developed, will be a study of nutrient isotope availability on Indonesian and Malayan estates. Tracers are also being readied for gathering further information on the mechanism of rubber formation from simple organic precursors.

The rubber tree presents many fascinating and complex problems that can be investigated to best advantage at a large research center of the type surrounding the tropical greenhouse. Trained technologists and elaborate equipment are available to use as required to meet these complex problems. The steady increases in rubber yields accruing from fundamental investigations attest that no plant studied by man has been more responsive to careful technical consideration.

References

1. Dijkman, M. J. Hevea, thirty years of research in the Far East. 1951.
2. Grantham, J. Manurial experiments on *Hevea*. Arch. Rubbercult. **8**: 501. 1924.
3. Rhines, C. E., McGavack, J., and Linke, C. J. Mineral Nutrition of *Hevea Brasiliensis*. Rubber Age. 1952. [p. 467.]
4. Chapman, G. W. Plant hormones and yield in *Hevea brasiliensis*. J.R.R.I.M. **13**: 167. 1951.
5. Beaufils, E. R. Mineral diagnosis of some "*Heveas brasiliensis*". Arch. of Rubber Cult. **32**: 1. 1955.

Utilization Abstract

Licorice. Roots of the licorice plant (*Glycyrrhiza glabra*), a perennial legume, are the source of licorice extract. Spain, France, Italy, Greece, Turkey, Syria, Iran, Iraq, Russia (Volga and Black Sea areas), and Manchuria are the principal licorice growing regions. Washed and coarsely ground licorice roots are extracted in boiling water, sometimes under pressure. The extract is filtered or decanted, then evaporated to a moisture content of about 20%, and finally molded into blocks ("brick licorice") or rolled into bars. Licorice manufacture is carried out principally in Italy and Asia Minor, but also in Spain, Greece, and France. Large amounts of licorice roots, mainly from Turkey, are imported into the United States for processing.

After the primary extraction, the root residue can be used for additional extracts that, because of their foam-producing properties, are utilized in foam fire extinguishers. The spent roots may be converted into paper pulp.

To a great extent licorice confections, which are more popular in Europe than in the United States, derive their characteristic flavor from oil of anise. Licorice extract is added to certain types of chewing gum to insure a flexible texture and to certain chocolate candies to stabilize the fat dispersion. Especially in the United States much licorice is used by the tobacco industry in cigarettes, cigars, smoking mixtures, chewing tobacco, and even snuff. Licorice added to tobacco imparts a sweet taste and characteristic flavor and also enhances the mildness of a mixture. Licorice in beer increases the foaminess of the beverage. In other drinks, such as root beer, porter, and stout, licorice is added for flavor. Licorice may also be used as a brown coloring matter.

Licorice has been used medicinally for many centuries mainly to mask the bitter or acrid taste of other drugs or as a soothing remedy for affections of the respiratory tract. Recently the extract has been shown to be of value in the treatment of gastric ulcers and has shown promise against Addison's disease.

Two of the glycosides in licorice root have been studied. These are liquiretin and glycyrrhizin. The latter is 50 times as sweet as sugar. (C. Nieman, *Advances in Food Research 7: 339–381. 1957.*) (JWT)

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The Puerto Rican Chironja—*New All-Purpose Citrus Fruit*

The chironja, an apparent natural cross of grapefruit and orange, combines the flavors and other highly desirable characteristics of both parents, offering vast new possibilities for development, both for fresh market and industrial purposes.

CARLOS G. MOSCOSO [1]

The chironja, a new member of the citrus family, recently found growing wild in the mountains of Puerto Rico, has aroused widespread interest of citrus growers and researchers during the past year.

The name "chironja" (*pronounced cheer-own-ha*) was given to the fruit shortly after its discovery in 1956. Chironja is a combination of the first syllable of the Puerto Rican word china, meaning orange, and the last two syllables of the Spanish word toronja, meaning grapefruit.

This new fruit, apparently a natural cross between the orange and grapefruit, combines highly desirable characteristics of both parents. It usually approximates the average grapefruit in size, although some larger specimens have been observed. When ripe, the inner juicy pulp is orange in color, and the outer rind becomes a bright, glossy yellow. The flavor of the fruit is a tantalizing combination of both the grapefruit and orange, without the bitterness of the former or the acidity of the latter.

I have called the chironja the "All-Purpose Citrus Fruit" because of its many uses. It may be cut in half and eaten like a grapefruit, with the advantage of no necessary addition of sugar or preparation with a grapefruit knife. The chironja may be peeled and eaten in sections like a tangerine. The rind, which has no unpleasant bitter taste, can be utilized for marmalade or candied peel. This fruit may also be squeezed for juice like an orange, the juice of one average chironja yielding the equivalent of 2 or 3 Valencia oranges. It is easy to squeeze by hand.

Although research on the chironja is still in the initial stages, I believe that this fruit has great potentialities for future development, both for fresh market and industrial purposes.

Origin and History

My first observation of the chironja occurred in November, 1956, while I was in charge of the Citrus Marketing Project at the Agricultural Experiment Station of the University of Puerto Rico. In this project, we were attempting to coordinate economic, horticultural, and agronomical research in order to study at close range the faults in the island's citrus marketing system, with efforts to improve it. We made many field trips into the interior coffee zone of Puerto Rico to interview citrus growers and to look for new and promising varieties of citrus among the thousands of native orange seedlings growing wild in this area.

It was on one of these field trips, accompanied by project co-leaders Raul

[1] Horticulturist, Specialist in Fruits, Agricultural Extension Service of the University of Puerto Rico in cooperation with the United States Department of Agriculture.

Pedraza and José A. Olivieri, that I first observed the tree, now known as the Puerto Rican chironja, growing wild in the Angeles and Caguanas rural section of the municipality of Utuado, Puerto Rico. It should be remembered that the bulk of the Puerto Rican orange crop is produced in this mountainous coffee zone of the island. The farmer utilizes orange and some grapefruit trees as shade for his coffee trees. The citrus crop is of secondary importance usually, and in many groves the trees are growing in a wild state.

While interviewing one of the farmers and looking over his orchard, I was impressed with the appearance of one unusually large, robust tree, laden with very large, bright yellow fruit. This tree was quite different in appearance from the surrounding common orange and grapefruit trees. Upon tasting the fruit I was amazed to discover that here was a delicious combination of both orange and grapefruit flavors. It seemed as though nature had combined the best genes of both parents to produce a new and delectable citrus delicacy.

When I questioned the farmer on whose land the tree was found growing, I was surprised to learn that this particular tree and several others growing on nearby farms were all propagated from seed. Evidently the few farmers who possessed these unusual trees had never marketed any of this fruit on a commercial scale, but rather, in view of its superior flavor and keeping qualities, had preferred to harvest the crop only for the consumption of their immediate families. I was told that occasionally small quantities of the fruit had been sold locally at relatively high prices in response to the demand of a few local consumers.

On this occasion, and on subsequent trips to the area, I brought back propagating material for making grafts and also some seed. I reported my observations to Mr. Arturo Roque, our Experiment Station Director, and to Dr. B. G. Capo, our Associate Director for Research. They were interested in my observations, and early in 1957 we decided to initiate propagation of this new fruit for experimental purposes.

We have not yet arrived at definite conclusions concerning the origin of the Puerto Rican chironja. Apparently some of these trees have been growing in isolated areas of the coffee zone of Puerto Rico for a number of years, unknown to the public. We have interviewed a large number of farmers in the region where I first observed the trees in November, 1956, and there are many conflicting, unconfirmed stories as to the origin of the trees. However, all reports coincide in one important detail, and that is that the trees were propagated from seed.

We have corresponded with citrus Experiment Stations in the continental United States and many other citrus producing areas throughout the world; and we have consulted all available botanical references in an effort to ascertain whether or not this fruit has been reported or described previously. To date, there is no record indicating that such a fruit has ever been officially reported or described in the literature.

Evidently the Puerto Rican chironja is the result of a spontaneous cross between the orange and grapefruit, resulting apparently in a new member of the citrus family. We have propagated a large number of these trees from seed at the Corozal and Lajas Substations of the University of Puerto Rico for the purpose of determining any changes in characteristics of the fruit. In over 100 seedling trees which I have observed so far, all have been true-to-type for the characteristics of the chironja. In no instance has the fruit reverted to either orange or grapefruit. Although in some cases there is a slight variation in size and shape of the fruit when propagated by seed, the flavor and other character-

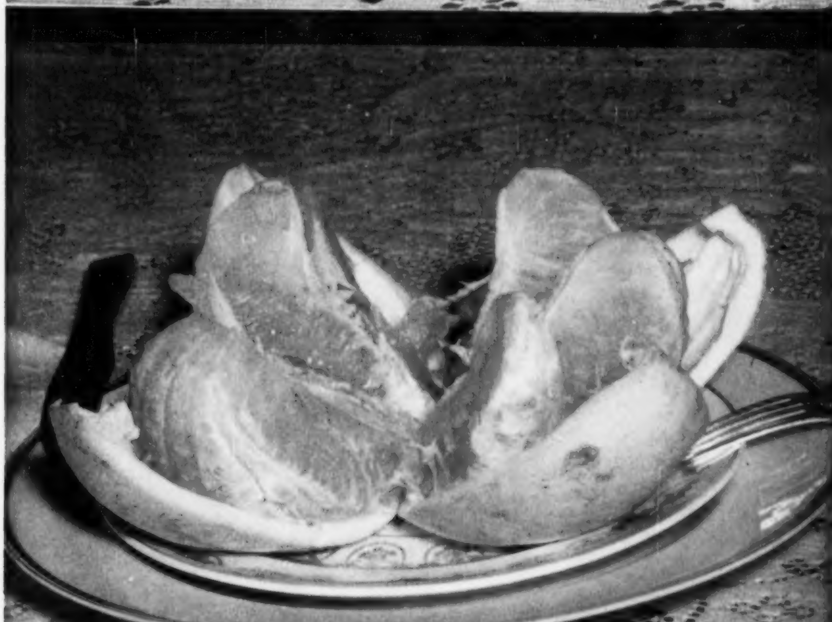


FIG. 1 (Upper). Chironja may be cut in half and eaten like a grapefruit. No sugar needed. No preparation with grapefruit knife necessary.

FIG. 2 (Lower). The chironja may be peeled and eaten in sections like a tangerine. It peels easily and is not sticky. The rind may be used for marmalade or candied peel. There is no unpleasant bitterness.

istics of the chironja remain constant. This slight variation in size and shape of fruit within this type of citrus is comparable to similar variations in seedling oranges and grapefruits.

Questions have arisen as to the possible similarity of the Puerto Rican chironja and those hybrids referred to in the literature as "orangelo", (cross between the sweet orange *Citrus sinensis* and the grapefruit *Citrus paradisi*), and the "tangelo", (*Citrus paradisi* XC, cross between the tangerine and grapefruit). A close study of the descriptions of these hybrids and comparison with the chironja reveal some interesting similarities; but on the other hand, too many differences in characteristics exist to classify this new fruit as a variety of either of these hybrids.

We have now observed enough seedling trees to establish the preliminary conclusion that the seed of the Puerto Rican chironja is true to type. This characteristic and certain other peculiar characteristics of the fruit, plus the fact that the fruit has never been recorded previously, lead us to believe that the chironja is a new and different type of citrus.

Similar hybrids have been observed in other Caribbean islands, but none of these fruits so far presents exactly the same characteristics as the Puerto Rican chironja. During a recent visit to the Republic of Haiti, I myself observed a citrus fruit which presented some characteristics similar to the chironja. However, upon careful comparison of the characteristics of the two fruits, I found certain obvious differences. The Haitian fruit was smaller in size, different in shape and flavor, and I did not observe in any instance the bright yellow color of the ripe chironja.

Another hybrid which should be mentioned is the Jamaican "ugli". This fruit has been produced in the island of Jamaica for many years. I have consulted a number of friends and authorities who have had the opportunity to observe and taste both the ugli and the chironja, and their opinion is that these are two different hybrids. This opinion is substantiated upon comparison of the characteristics of the chironja with the description of the ugli as given in Citrus Industry, Vol. I, **1948**.

Preliminary Description of the Puerto Rican Chironja[2]

The Puerto Rican chironja is a citrus fruit which appears to be a natural cross between an orange and a grapefruit. It undoubtedly develops from a nucellar embryo because there is very little if any difference between the parent and the many seedlings.

It is a large columnar tree when grown in partial shade; but several trees examined that were growing in full sunlight had the typical rounded growth of the orange and grapefruit. Some young twigs, and especially the fast-growing water shoots, produced slender to rather stout thorns which are much like those of a young seedling grapefruit.

The leaves are similar to those of the grapefruit in having a similar aroma when bruised, the deep green color, the heavy, thick texture, and the prominent wing on the petiole of most leaves. They differ from the grapefruit in that they are noticeably deformed and irregularly undulated on apparently healthy trees. The larger leaves are somewhat shorter and wider, concave, and slightly arched.

The fruits are usually borne singly on the ends of branches and compare in size with the grapefruit. The shape is globose to pyriform and somewhat obloid. The base or stem end is very slightly to prominently collared and depressed. The collar or shoulder is longitudinally fur-

[2] This description was prepared through the cooperation of Mr. Roy Woodbury, Taxonomist, University of Puerto Rico, Agricultural Experiment Station.

FIG. 3. Mrs. Carlos G. Moscoso squeezes king-sized chironja from which she obtained one full glass of juice.

rowed or ridged. The apex has a very small stylar scar surrounded by a prominent gray to tan area approximately one-half inch in diameter. The outer rind is much like the grapefruit in aroma, but with a much more pleasing appearance. It has a radiant yellow color which is usually unblemished by rust or

scab. The inner white pulp or rind does not have the bitter quality of the grapefruit, but rather the pleasing sweetness of the orange. It is of medium softness, with inconspicuous vascular bundles, and it separates easily from the segments.

The edible portion of the fruit contains nine to eleven very large segments which adhere only slightly to the rind. The septa or thin covering of each segment is very tender and may be eaten without distaste.

The clear, mild-flavored, sweet juice is contained within very attractive large yellow-orange vesicles that are attached to the septa by a noticeable white thread. The vesicles are easily separated from one another. The mild-flavored juice, being neither acid nor bitter, has a very pleasing taste which is a combination of both orange and grapefruit flavors. There is little acid or bitterness even in the immature fruit. The fruit contains few seeds.

From a scientific standpoint it appears that this new type of citrus cannot be classified either as an orange or as a grapefruit. It presents marked characteristics of both parents, in the appearance of the tree and foliage as well as the fruit.

I wish to emphasize that this is a preliminary description of the chironja, based on observations and findings up to date. This is a new fruit, still under study. As research on the fruit progresses, more specific measurements and more details concerning characteristics of the fruit will be reported in technical publications.

Present Work and Future Outlook

Since the chironja is a very recent finding, no research work had been done with this fruit prior to February, 1957. Upon obtaining grafting material and seeds to initiate experiments with this fruit, 290 grafts were made at the Trujillo Alto substation of the Agricultural Experiment Station at the University of Puerto Rico. Seeds were planted at the Rio Piedras Main Station to obtain new seedlings for studies on the behavior of the progenies and for selection of desirable types.

On March 1, 1957, the Chironja Project, "Selection and Production of the Chironja Fruit for Fresh Market and Industrial Purposes", was authorized by the Director of the Agricultural Experiment Station of the University of Puerto Rico.

Later in the year, over 300 more grafts were made, using different root stocks. Small, one-acre chironja orchards were planted during 1957 at five substations in Puerto Rico to study the effect of different soil and climatic conditions using these different root stocks.

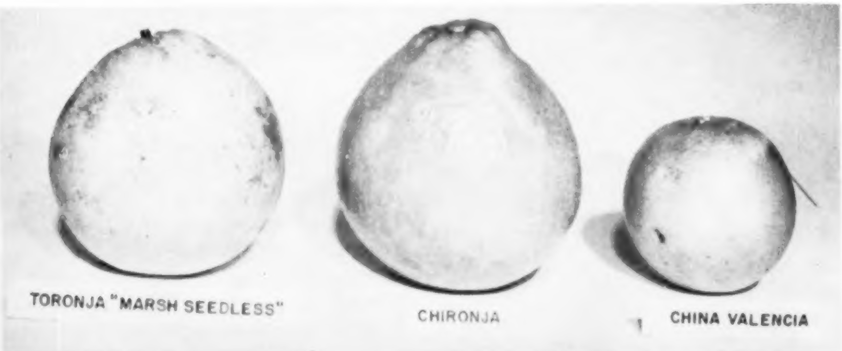
I was able to make three initial selections of the chironja among the trees found growing wild in the western central part of Puerto Rico. These selections are: Chironja T-1 (for appearance, shape, and productivity), Chironja B-1 (for late-yielding purposes), and Chironja L-1 (for general appearance and yield). Selection of superior fruit will be made and propagated; and if results merit, new varieties may possibly be developed by breeding in the future.

Preliminary observations are being made to record characteristics of the fruits, quality of the progenies, yield, and blooming and fruiting periods. We have already observed that some varieties of chironja bear off-season fruit. In several earlier-bearing varieties, the fruit may hang on the tree for an exceptionally long period without spoiling. General morphology studies will be made of the progeny trees, noting any variation tendencies and stability of types.

Observations of the original parent trees will be made, noting periods of blooming, fruiting, and harvest; yield and quality of fruit; uniformity as to shape, size and flavor of the fruit. The

data obtained from these observations will be used as a basis for comparison of the fruit developed by selection and possible breeding in the future.

In addition to the hundreds of grafts already made, more grafts from the parent trees will be made, using different root stocks. Study and observation of development of the tree; 2. age of tree at first blooming and fruiting; 3. quality of first fruit; 4. period of blooming, fruiting and harvesting; 5. yield; 6. quality of fruit in mature bearing trees, including the factors of shape, color, size, texture, structure, flavor, uniformity, number of seeds, keeping qualities, suitability for



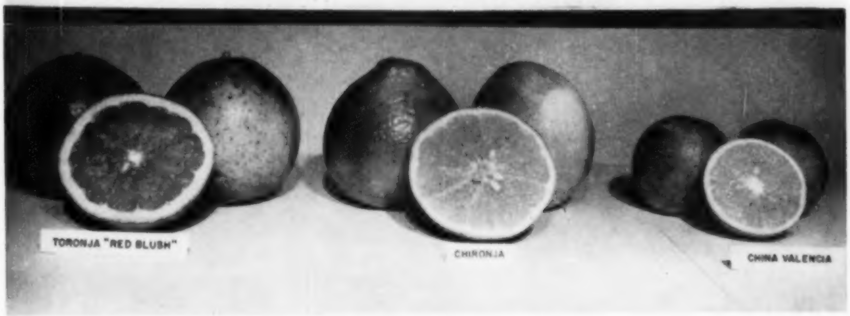


FIG. 4 (Upper). From left to right showing the size of the chironja. Grapefruit Marsh Seedless, chironja, and Valencia orange.

FIG. 5 (Lower). Cross section study. From left to right a comparison of the Red Blush grapefruit, the chironja, and the Valencia orange.

these grafts will be made, noting general behavior, yield and quality of fruit.

Observations are being recorded of the progeny seedling trees grown from the seeds of the parent trees at the Corozal Substation. In all of these studies and observations the following points will be of especial interest to citrus growers everywhere: 1. habit of growth, vigor, canning and other processing, and chemical analysis of vitamin content.

All progeny fruit will be compared with fruit of parent trees. Experiments have been initiated with different treatments and cultural methods to observe effect on quality and yield of the fruit, noting especially the effects of fertilizers, pruning, insecticides and fungicides. From

a commercial standpoint the chironja offers the advantage of utilization in at least three different ways by fresh market consumers. Its high productivity, delicious and distinctive new flavor, excellent keeping qualities, and natural attractive appearance without the use of color additives are other factors in its favor. Forthcoming experiments will demonstrate its suitability for canning and other processing.

In a recent small-scale market trial, approximately 300 ripe chironjas were brought from Mr. Gil Boneta's farm in Barrio Caguana, Utuado, P. R., to be sold at a small specialty grocery store in metropolitan San Juan. The chironjas were offered for sale at a price of 2 for 25¢ starting at 9 A.M., without any previous advertising. All the fruit was sold by 11:00 A.M. and early customers, including many tourists, were coming back asking for more chironjas.

Interest in this new fruit continues to grow. Since publication of the first official release of information on the chironja by the University of Puerto Rico Agricultural Experiment Station in 1957, we have received hundreds of letters of inquiry from interested individuals from all parts of the world. Small farmers, large citrus growers, nurseries, commercial processing plants and researchers are constantly requesting seed and more information concerning this new fruit.

Up to the present time we have been able to give out only limited information on the fruit, since research is still in the early stages of development. The Agricultural Experiment Station of the University of Puerto Rico has not been able to furnish propagating material of the chironja, due to the scarcity of this material, even for experimental purposes. However, it is hoped that some seed and possibly budwood for grafting and some seedling trees may become available for distribution by 1960.

Several newspaper and magazine articles have been published in Puerto Rico, the United States and South America concerning the commercial possibilities of this fruit. The finding of the Puerto Rican chironja may open the door to a new field of research in citrus fruits and new and profitable developments for the citrus industry.

Tarahumar Fish Stupefaction Plants

Fish stupefaction is practised throughout the year among the Tarahumar of Western Chihuahua, Mexico, but is especially important between March and June, when food reserves are low. In the areas occupied by these people, plants from 13 different families of flowering plants provide either piscicidal or stupefaction properties. The method of use, stupefying principle, parts employed, and potency of the individual plants are quite variable.

CAMPBELL W. PENNINGTON [1]

The Tarahumar are a semi-nomadic agricultural people who occupy uplands and barrancas of western Chihuahua. Although their subsistence is derived chiefly from cultivated plant products and collected wild foods, fish stupefaction is important in their economy during the entire year, especially between March and June, when food reserves from the preceding year's crops have been depleted and wild plants used as food have not yet sprouted or fruited. Stupefaction is apparently most prevalent today in those areas where Tarahumar are least affected by outside contacts.

Mixing of toxic substances in still water is achieved by agitation of the water with a stick coincident with insertion of poison-bearing material, or crushed plant material is placed in a basket which is doused in the water. Commonly, for stupefaction in slowly moving water, great masses of crushed materials are dumped into the stream. During the rainy seasons, rivers and streams of western Chihuahua are swift and turbulent, but except at high water periods there are pools where stupefaction of fish is easily accomplished. Where water is moving too rapidly for effective stupefaction, the Indians construct dams, nabóara, that slow the water. These nabóara range from a small rock structure thrown up across a shallow stream to elaborate structures of stone backed by branches, leaves, mud and other debris.

The earliest reference to fish stupefaction among the Tarahumar is found in an account written by a Franciscan priest, Fermín de Estabillo (7), at San Miguel de Las Bocas, the present Villa Ocampo, Durango, in 1777. The Tarahumar "filled" the river with a plant called barbasco in order to stupefy fish. Use of this plant was claimed to be very harmful to pregnant domestic animals, especially the cows when they drank in the river, even when they drank a league downstream from where plants were used. Cows died from the poison, but mares only had miscarriages! Subsequent investigators or travellers, as Schwatka (19), Lumholtz (13), Hrdlička (12), Basauri (1), Bennett and Zingg (2) and Gajdusek (9) have documented the importance of plants as piscicides.

Liliaceae

Siríki (*Yucca decipiens* Trel.) is rare in eastern and southwestern Tarahumar country, but plentiful in the northwest, in canyons and on upper slopes, where it is associated with scrub vegetation on rocky, sunny exposures. Roots and leaves are crushed on a stone and dumped into

[1] Assistant Professor of Geography, University of Utah. Grateful acknowledgment is made to David Brambila, S.J., of Norogachi, who shared generously his knowledge of Tarahumar material culture.

pools or slowly moving water. A large quantity of this material is required when water is moving.

Schwatka (19) commented that the Tarahumar "build dams in the mountain streams and poison the fish that collect therein with a deadly plant the Mexicans call 'palmilla', securing everything, fingerlings and all". Identification of this palmilla is impossible, but it probably does not refer to an *Agave*, which is generally known as maguey or mescal in northern Mexico. Reference may be to a species of *Yucca* or *Nolina*, for *Yucca decipiens* Trel., *Dasylirion durangense* Trel., and *Dasylirion wheeleri* S. Wats. are known by Mexicans in western Chihuahua as palma, palmilla or sotol, and by Tarahumar as siríki. *Nolina durangense* Trel. and *Nolina matapensis* Wiggins, which are not unlike yuccas in appearance, are known among Mexicans as palmilla and among Tarahumar as gurú.

The writer knows of no specific toxic substance that has been demonstrated for *Yucca decipiens* Trel., but various alkaloids and glucosides have been found in yuccas from southwestern United States and northwestern Mexico (22), and Cheney (4) has stated that a stem and leaf extract of *Yucca glauca* Nutt. has been used as a source of arrow-tip poison in Arizona and Mexico.

Processed roots of siríki are a favorite food among the Tarahumar, and saponaceous qualities of the roots are appreciated by Indians and Mexicans.

Amaryllidaceae

Sóko (*Agave schottii* Engelm., *Agave lechuguilla* Torr., and an unidentified *Agave*), which is readily available almost everywhere in western Chihuahua except in meadows and pine-clad uplands, is widely used as a piscicide. Another *Agave* (*A. bovicornuta* Gentry), apparently limited to middle western canyon slopes in Tarahumar country, is also used. Hearts, leaves and roots from these plants are crushed and thrown into pools or slowly moving water. Piles of used bast are seen in and along stream beds of western and south-eastern Tarahumar country today, particularly in April and May.

One or more of these plants must be among Agaves mentioned by Lumholtz (13) in connection with fish stupefaction. He reported that "when fishing is to be done on a somewhat extensive scale, two species of agave—the amole (the soap plant) and the soke [sóko ?]—are used". He also noted that plant leaves were pounded with stones and trampled upon by men "to make the juice come out". This piscicide was effective for some three hundred yards downstream. Today, several crushed hearts and roots or ten or fifteen large leaves obtained in the spring provide enough toxic substance to stupefy fish for more than three hundred yards downstream, if the water is not moving swiftly. Carlos Basauri (1) also reports an amole used as a piscicide.

Although little is known of toxic principles in these plants recent studies have demonstrated traces of sapogenins in certain species of *Agave*, and specific traces of gitogenin and tigogenin have been isolated from *Agave schottii* Engelm. (21). Muenscher (15) records a toxic substance in *Agave lechuguilla* Torr. Caustic properties of *Agave bovicornuta* Gentry are well known to Tarahumar who live on middle slopes of western canyons. Excrescence from leaves is used on sores, and repeated applications tend to dry up festering sores. Toxic properties of these piscicides are also attested to by the fact that when used as food, mescal, they are processed by baking. Saponaceous qualities of *Agave schottii* Engelm. and *Agave lechuguilla* Torr. are employed in washing blankets.

Iridaceae

Sa'pari or sa'paríki (*Sisyrinchium arizonicum* Rothr.) grows thinly under pine in uplands near Sitenápuchi and Narárachi. Roots are crushed and dumped into pools of water. It is claimed that this piscicide is not effective in running water. No data are available on the precise toxic substance in sa'parí, but the iris family is well known for its active physiological constituents, alkaloids and glucosides.

Juglandaceae

One of the widely distributed trees along water courses in western Chihuahua, except in uplands proper, is lači (*Juglans rupestris* Engelm.). Tender young leaves and bark are crushed and thrown into streams, or, material is put in a basket which is sloshed about in pools. Leafing of this tree comes at a time when food supplies are becoming scarce, and the leaves and bark are much used as a piscicide.

Hicoriaceae

Another lači[2] (*Carya illinoensis* (Wang.) K. Koch), a pecan that grows to great heights along streams in well-watered ravines in the eastern foothill region, supplies leaves and bark used in fish stupefaction. Young leaves are bundled, crushed and thrown into pools or slowly moving water.

Polygonaceae

An aquatic and land plant, korísowa (*Polygonum punctatum* Ell.) that is found growing rankly near Norogachi and Sitenápuchi, is an important piscicide. A great quantity of this plant is bundled, crushed and dumped into a large basket which is slowly dipped in and out of pools of water until the water turns green. Fish rise to the surface almost immediately. Specific toxic substances have not been determined for *Polygonum punctatum* Ell., but it is reported to cause dermatitis (15).

Yet another *Polygonum*, watonáka (*P. pennsylvanicum* L.), is apparently more widely distributed in western Chihuahua than *Polygonum punctatum* Ell. Efficacy of watonáka as a piscicide is reflected in its Mexican name, yerba del pescado. It is used precisely as korísowa. The toxic substance in this plant is unknown, but it is known to cause dermatitis and photosensitization, and smuts (fungus infections) on the plant are very irritating to the skin (16).

One of these plants must be the *Polygonum* mentioned by Lumholtz (13) as a piscicide used by upland Tarahumar. The plant was "pounded with stones and thrown into the small corrals [fish traps, nabóara]".

Either of these plants serves as greens but only after they are boiled and drained. A small quantity of *Polygonum punctatum* Ell. is said to give piquancy to esquiate, an important corn food among the Tarahumar. The pepper-like quality of this plant is indicated by its name, korísowa, for korí is the Tarahumar term for chile peppers (*Capsicum annuum* (*Capsicum frutescens*) L.).

Rosaceae

A widespread native fruit tree supplying an edible fruit in northern Mexico is usábi (*Prunus capuli* Cav.), and cultivated or wild, the tree supplies leaves and bark used as a piscicide in uplands. Young tender leaves and bark are bundled, crushed with a wooden mallet or stone and dumped into pools or slowly moving water. Great quantities of this material are needed. The toxic elements involved are undoubtedly cyanogenic glucosides, for bark, leaves and seeds of this tree, upon hydrolysis, have yielded such elements (20).

[2] The Tarahumar applies this term to any tree that bears an edible nut.

A small amount of usábi is used in preparation of a tea taken for whooping cough, and young leaves are claimed to give piquancy to esquiate. Utilization of small amounts of leaves as a condiment and in a medicinal preparation suggests that, whatever the toxic element may be, it is not harmful in small amounts. Practical experience must have demonstrated that large amounts of the material are required for fish stupefaction.

Fresh leaves of túrusi (*Prunus persica* (L.) Batsch), an introduced tree (8), and ča'gúnari (*Purshia tridentata* (Pursh) DC.) are bundled, crushed and dumped into pools of water. Young leaves of ča'gúnari are claimed to be effective in drying up skin infections.

Leguminosae

Nawé or nawéke (*Tephrosia leiocarpa* Gray), which grows in shady ravines in uplands between Sitenápuchi and Pawiciki, has a large root which is crushed and mixed with sand in a basket. This basket is sloshed about in pools for a short time. This plant is probably the nawé which Carleton Gajdusek was told of when he visited Norogachi in 1953 (9).

Although various species of *Tephrosia* are used in fish stupefaction over the world, we know little of their toxic properties. However, tephrosal and tephrosin have been isolated from one species, *Tephrosia vogelii* (16). Tarahumar use crushed roots of nawé as a poultice to kill lice on animals and humans.

Karároa or garáowa (*Mimosa dysocarpa* Benth.), a many-branched shrub found in thick stands along streams near Sitenápuchi and Norogachi, has very large roots which are crushed and thrown into slowly moving water. When used in pools, roots are basketed and sloshed in the water. The precise toxic quality is not known, but *Mimosa pudica* L., a closely related plant, has yielded mimosine, an alkaloid, from sap of sprouts and roots (11, 14).

According to Bennett and Zingg (2), roots of *Tephrosia talpa* Wats. (*Cracca talpa* Rose) are pounded, mixed with earth and thrown into slowly moving streams as a piscicide.

Rutaceae

Bennett and Zingg (2) also record use of *Casimiroa edulis* Llave. and Lex. and *Casimiroa sapota* Oerst. as fish stupefaction agents. Bark of these plants is crushed and thrown into water. Standley (20) notes that bark of both trees contains a hypnotic glucoside, casimirosine.

Euphorbiaceae

The dominant piscicides in canyons of the Urique and Fuerte rivers are *Sebastiania pringlei* Wats. and *Sapium biloculare* (Wats.) Pax, which are known by Mexicans as yerba de la flecha. Bark of young trees is beaten with a wooden mallet or stone and dumped into moving water. This bark must be handled carefully, as milky juice exuded irritates hands or eyes.

Use of these plants as a source of arrow poison and as a fish stupefaction agent is apparently a very old practice in northwestern Mexico. Father Juan Nentuig, author of the "anonymous" *Rudo Ensayo* (17), refers to an arrow poison plant called mago by the Opata, a tribe who lived northwest of the Tarahumar in the eighteenth century. The tree was small, "very green, luxuriant and beautiful to the eye; but it contains a deadly juice which flows upon making a slight incision in the bark. The natives rub their arrows with it . . ." (18). This is probably the arrow tree referred to by Clavijero, who, writing in the eighteenth century, mentioned an arrow tree used by Indians along the Sonora coast as a source of poison (6). Edward Palmer found Tarahumar at Batopilas

using a *Sebastiania* for poisoning arrows (**23**), and today, the Varohio, a tribe living west of the Tarahumar, use *Sebastiania pringlei* Wats. and *Sapium appendiculatum* (Muell. Arg.) Pax and Hoff. as piscicides (**10**). In the late nineteenth century, Lumholtz (**13**) recorded a yerba de la flecha used as a piscicide by Tarahumar.

Bradley (**3**) has shown that toxic qualities in *Sapium biloculare* (Wats.) Pax are contained in the latex. The qualities "consist of an alcohol-soluble resin, which is toxic to warm-blooded animals, and a water-soluble saponin, which is poisonous to fish".

Umbelliferae

Wašia (*Conium maculatum* L.), the poison hemlock of Europe, grows thickly in colonies under pine at Samachique and is one of the significant upland piscicides. Used only when the plant is in bloom, the root is crushed and thrown into slowly moving water. The Tarahumar state that very little of the plant root is required and that the root is never used in pools of water. Narcotic qualities of this plant are well known (**5, 24**).

This plant is presumably of European origin (**8**), but just how and when it reached Chihuahua uplands and how the Tarahumar learned of its narcotic potential cannot be determined. However, the oft-repeated statement that the plant is used only when in bloom suggests that the Indian must have experimented with it in some fashion. It is known to be nearly harmless in the spring but very dangerous afterwards (**15**).

Another wašia, *Ligusticum porteri* C. and R., which resembles *Conium maculatum* L., is found in western Chihuahua uplands and in damp shaded ravines near Norogachi. Roots are used as a piscicide as those of the hemlock. Resemblances between *Ligusticum porteri* C. and R. and *Conium maculatum* L. may be of significance. The former is apparently not an introduced plant, and vegetative resemblances between the two —and the known potency of the former —might have prompted experimentation with the hemlock. However, we cannot be certain that the hemlock is an introduced plant. *Ligusticum porteri* C. and R. is used medicinally; the hemlock is not.

Polemoniaceae

Ipomopsis thurberi (Torr.) Grant ? (*Gilia thurberi* Torr.), known at Norogachi and Sitenápuchi as matéšuwa, grows on shady, damp slopes, generally under pine, in rather thick litter. A small quantity of leaves and roots is crushed and placed in a basket which is sloshed in running water.

Gajdusek (**9**) records another matéšuwa, *Gilia macombii* Torr., as the most potent piscicide near Norogachi. Except for the root, the entire plant is crushed between rocks in a slowly moving section of a stream. A few armloads of this plant are required to cause fish to rise to the surface several hundred yards downstream.

Gajdusek documented efficacy of this matéšuwa in a laboratory experiment. A filtered, cold aqueous extract made from powdered dried plants in a concentration of 1.0 mg./ml. was sufficient to stun goldfish in ten minutes and to kill them in less than fifty minutes. The fish rose frequently to the surface to gather air, they lost their equilibrium and lay on their sides, and became inactive except for quick, jerking movements before dying. An extract made from only 0.2 mg./ml. of the dried powdered plant killed goldfish in two to two and one-half hours (**9**).

Specific toxic elements in these plants are not documented, but related species, *Gilia achillaefolia* Benth., *Gilia aggregata* Gray and *Gilia laciniata* contain

considerable amounts of saponins and are very poisonous (16).

Compositae

Čaʼguši (*Bacharis glutinosa* Pers.) grows in thick stands along stream courses in drier parts of eastern Tarahumar country where it is known by Mexicans as jarillo del río or vara dulce. Young stems and leaves are crushed on a rock and placed in a basket which is sloshed in slowly moving water behind a stone or brush fish trap. The poisonous principle is unknown, but cattle and sheep are known to have been poisoned from grazing a related species, *Bacharis ramulosa* (DC) Gray (15). Crushed leaves are demonstrably effective for clearing up skin infections which are common among the Tarahumar. In the upper Río Conchos region, čaʼguši served not long ago as a famine food, but only after processing of young roots which were roasted on hot coals.

Tarahumar living in eastern foothills maintain that the most potent piscicide is *Dyssodia anomala* (Canby and Rose) Robins., which is known as matéšuwa. The plant is commonly found in shady areas near water. Leaves and roots, which have a considerable odor, are crushed and thrown into a pool of water. The Indian states that only a small amount is required where fish are trapped in large pools, a common occurrence during the dry season in western Chihuahua. The saponaceous element in this plant is utilized by Mexicans and Indians; the former know the plant as jaboncillo.

Thus, three plants, *Dyssodia anomala* (Canby and Rose) Robins., *Ipomopsis thurberi* (Torr.) Grant ? (*Gilia thurberi* Torr.), and *Gilia macombii* Torr. are known among the Tarahumar as matéšuwa. Multiple use of this name poses no special problem, for a comparison of the plants indicates some vegetative resemblance. Leaves are pinnatifid, and without flowers all three appear similar.

Sopépari (*Senecio hartwegii* Benth.), a large shrub that is restricted to moist slopes of shady ravines in uplands near Norogachi, is claimed to be among the top five plants in potency as a piscicide. This plant is probably the sopero recorded as a piscicide by Basauri (1). Large leaves and roots are crushed and then placed in a basket which is dipped in and out of slowly moving water. Branches of this shrub maintain an odor after they are dried and stored for many weeks. The writer knows of no specific toxic property in this plant, but jacobine, a toxic alkaloid, has been found in a related plant, *Senecio jacobea* L.; *Senecio retrosus* and *Senecio aureus* are claimed to contain toxic substances (5, 15).

Another effective piscicide of the Compositae is keyóčuri or geóčuri (*Zexmenia podocephala* Gray), found as a perennial herb in the Urique canyon and at Norogachi and Sitenápuchi. The large tuberous roots and leaves are crushed and placed in a basket which is doused in a pool or still water or in slowly moving water. Roots of this plant are decocted in a tea taken for stomach disorders, and roots are traded by Indians to Mexicans who dispose of them to herbalists at Creel and Parral. Leaves of keyóčuri are eaten as greens after being processed.

Pungent roots of nakáruri (*Vigueria decurrens* Gray), known among Mexicans as espantamula or yerba de la mula and found in damp places along ravines in southeastern Tarahumar country, is one of the easily stored piscicides. When fresh roots are used in stupefaction, they are crushed slightly and dumped into the water. Dried roots are mashed thoroughly, soaked for several hours and then thrown into pools. Crushed roots are used medicinally as a poultice for boils and other skin infections. This

plant is apparently not harmful to animals, and it is a significant browse plant in western Chihuahua.

Roots and stems of a small shrub, *Stevia salicifolia* Cav., are used precisely as nakáruri. It is a common medicinal plant among the Tarahumar, and like a related plant, *Stevia serrata* Cav. (ronínowa), has a decidedly astringent or drying effect when chewed. Both plants are sought as a remedy for severe toothache.

Bennett and Zingg (2) record *Cacalia decomposita* Gray as a piscicide. The plant is found in canyons, uplands and in eastern foothills, but everywhere the Tarahumar deny its use as a fish stupefaction agent, stating instead that it is used extensively for medicinal purposes.

Unidentified Specimen

Roots of anači, a tiny spiny plant that grows on rocky terrain on hills near Norogachi, is chewed by children and adults as a gum, yet a great quantity of the roots, when thoroughly mashed and soaked for several hours, is an effective piscicide in pools of water.

Résumé [3]

Plants	*Part Used*	*Reference*
Agave bovicornuta Gentry	Roots and leaves	No. 100 (Univ. of Texas)
Agave lechuguilla Torr.	Roots and leaves	No. 70
Agave schottii Engelm.	Roots and leaves	No. 147
Agave species	Roots and leaves	No. 71a; Lumholtz (13)
Bacharis glutinosa Pers.	Leaves and stems	No. 588
Cacalia decomposita Gray	Entire plant	Bennett and Zingg (2)
Carya illinoensis (Wang.) K. Koch	Leaves and bark	No. 632
Casimiroa edulis Llave. and Lex.	Entire plant	Bennett and Zingg (2)
Casimiroa sapota Oerst.	Entire plant	Bennett and Zingg (2)
Conium maculatum L.	Roots	No. 726
Dyssodia anomala (Canby and Rose) Robins.	Roots and leaves	No. 499
Gilia macombii Torr.	Leaves and stems	Gajdusek (9)
Ipomopsis thurberi (Torr.) Grant ? (*Gilia thurberi* Torr.)	Roots and leaves	No. 107 (Verne grant)
Juglans rupestris Engelm.	Leaves and bark	No. 613 (Univ. of Texas)
Ligusticum porteri C. & R.	Roots	No. 652 (Univ. of Calif.)
Mimosa dysocarpa Benth.	Roots	No. 537 (Univ. of Texas)
Polygonum pennsylvanicum L.	Entire plant	No. 624
Polygonum punctatum Ell.	Entire plant	No. 658
Polygonum species	?	Lumholtz (13)
Prunus capuli Cav.	Leaves and bark	No. 561 (Univ. of Texas)
Prunus persica (L.) Batsch	Leaves and bark	No. 59
Purshia tridentata (Pursh) DC.	Leaves	No. 589
Sapium biloculare (Wats.) Pax.	Bark	No. 23
Sebastiania pringlei Wats.	Bark	No. 71
Senecio hartwegii Benth.	Roots and leaves	No. 646 (Univ. of Texas)

[3] Collection numbers in the reference column refer to plants collected by the writer during the spring and summer of 1955. Unless otherwise indicated, specimens are in the possession of the writer. Plant determinations were made by Marion Cave, Lincoln Constance, Verne Grant, Otto T. Solbrig and B. L. Turner. Numbers in parentheses refer to the bibliography.

Sisyrinchium arizonicum Rothr.	Roots	No. 629 (Univ. of Texas)
Stevia salicifolia Cav.	Roots and stems	No. 592 (Univ. of Texas)
Tephrosia leiocarpa Gray	Roots	No. 545 (Univ. of Texas)
Tephrosia talpa Wats. (*Cracca talpa* Rose)	Roots	Bennett and Zingg (2)
Viguieria decurrens Gray	Roots	No. 657 (Univ. of Texas)
Yucca decipiens Trel.	Roots and leaves	No. 129
Zexmenia podocephala Gray	Roots and leaves	No. 646 (Univ. of Texas)

Bibliography

1. Basauri, Carlos. Monografia de los Tarahumares. México. 1929. [p. 57.]
2. Bennett, W. C., and Zingg, R. M. The Tarahumara, an Indian tribe of Northern Mexico. 1935. [pp. 113, 122, 140, 170, 175-176.]
3. Bradley, C. E. Yerba de la flecha—arrow and fish poison of the American Southwest. Eco. Bot. **10:** 362–366. 1956.
4. Cheney, R. H. Geographic and taxonomic distribution of American plant arrow poisons. Am. Jour. Bot. **28:** 136–145. 1931.
5. Claus, E. P. Pharmacognosy, 3rd ed. 1956. [pp. 434–435, 531–532.]
6. Clavijero, Francisco Javier. The history of Lower California. Transl. by S. E. Lake and A. A. Gray. 1937. [p. 55.]
7. Estabillo, Fermin de. Relación de San Miguel de las Bocas. 1777. Photocopy in Dept. Geog. Univ. Cal., Berkeley.
8. Fernald, M. L. Gray's manual of botany, 8th ed. 1950.
9. Gajdusek, D. Carleton. Tarahumara Indian piscicide: *Gilia macombii* Torrey. Sci. **120:** 436. 1954.
10. Gentry, H. S. Río Mayo plants. Carnegie Inst. Wash. Publ. No. 527. 1942. [pp. 167–168.]
11. Henry, T. A. The plant alkaloids. 1949. [p. 4.]
12. Hrdlička, Aleš. Physiological and medical observations among Indians of Southwestern United States and Northern Mexico. Bull. 34. Bur. Am. Ethnol., Smithsonian Inst. 1908. [p. 25.]
13. Lumholtz, Carl. Unknown Mexico. Vol. **I:** 401–404. 1903.
14. Manske, R. H. F., and Holmes, H. L. The alkaloids. Vol. **I:** 211. 1950.
15. Muenscher, W. C. Poisonous plants of the United States. 1947. [pp. 9, 55, 63, 174, 220, 235–237.]
16. Pammel, L. H. A manual of poisonous plants. 1911. [pp. 421, 558, 843.]
17. Pradeau, Alberto Francisco. Nentuig's Description of Sonora, Mid-America. Vol. **35**(2): 81–90. 1953.
18. [Nentuig, Juan.] Rudo Ensayo. 1951. [p. 48.]
19. Schwatka, Frederick. In the land of cave and cliff dwellers. 1893. [p. 374.]
20. Standley, P. C. Trees and shrubs of Mexico. 1920–1926. [pp. 341, 527, 692.]
21. Wall, M. E., *et al.* Steroidal sapogenins, VII. Survey of plants for steroidal sapogenins and other constituents. Jour. Am. Pharm. Assoc., Sci. ed. **43**(1): 1954; **43**(8): 504. 1954.
22. Watson, S. List of plants collected by Dr. Edward Palmer in southwestern Chihuahua, Mexico, in 1885. Proc. Am. Acad. Arts and Sci. **21:** 414–455. 1886.
23. Youngken, H. W. A textbook of pharmacognosy. 1950. [p. 625.]

Bayberry Wax and Bayberries

The "wax" of various species of Myrica is not a true wax, but a vegetable tallow extracted from the surface of the fruits. The principal use of the "wax" is for Christmas candles, but it is also used in soap, ointments, leather-polishing formulations, etching, and medicinals.

LOUIS O. WILLIAMS[1]

Bayberry Wax and Bayberries

Bayberry wax, or myrtle wax, has no doubt been used since prehistoric times in the Americas and Africa, for it is easily extracted from the "berries" on which it occurs. All that is necessary is to collect the "berries" and to separate the wax from them by boiling with water. The wax was of importance as a source of illumination in colonial North and South America. Bayberry candles were a regular article of trade in New England and were used down to the beginning of this century. There are reports that the berries occasionally were collected and candles made from the wax until some 40 or 50 years ago. Bayberry candles are still to be had as a specialty but probably are now usually made from wax imported from Colombia or South Africa or from synthetic wax. Many modern bayberry candles may be made from a wax which contains only a small part of bayberry wax or perhaps may have only a coating of bayberry wax to lend fragrance.

Bayberry wax has long been used for candles in Mexico and may still be used in some isolated places. The wax is still found occasionally in markets in Mexico, but the nominal cost of kerosene in Mexico would almost preclude the use of the wax for candles.

In Guatemala and Honduras, the wax is still collected by the native peoples, usually to make candles for religious ceremonies of one kind or another. Candles made from myrtle wax are used in the curious pagan-Catholic rituals of the Indians in the churches in Chichicastenango. Candles from cheaper materials will doubtless displace those of myrtle wax before too long.

In Popayán, a picturesque colonial city in southern Colombia, candles made from bayberry wax (cera de laurel) are used in the classical religious processions of Holy Week.

Wax entered into the fabrication of golden ornaments in pre-Colombian Costa Rica and Panama. A system known as the "lost wax" method was used in these castings. It is possible that myrtle wax may have been one of the waxes used.

Bayberries probably have some 5 to 10 percent of wax by weight, although as much as 25 percent has been reported. The "wax" that the various species of *Myrica* yield is not a true wax, but rather a vegetable tallow composed largely of glycerides. It is usually classified as a wax, however, for its uses are those of waxes, and it can be blended easily with paraffins and with true natural waxes.

Bayberry wax is currently offered (April, 1958) in the New York market, wholesale, at 45–47 cents a pound. It was calculated that a collector in New England might collect the equivalent of four or five pounds of wax a day. Therefore, it is unlikely that the industry

[1] Economic Botanist, Crops Research Division, Agricultural Research Service, United States Department of Agriculture, Beltsville, Maryland.

will attract many workers in the United States. There is, however, a small amount of wax harvested each year, mostly in Massachusetts.

Mr. E. Schuemann of D. Steengrafe & Co., Inc., reports the following on imports of bayberry wax from Colombia: "Because of limited demand and low prices, production in Colombia declined gradually as natives found pay for other work more lucrative, but with a sharp increase in price late in 1956 and 1957, Colombia was induced to market enough of the wax to take care of the rather limited consumption". Mr. Schuemann also states that imports during 1956 were negligible, but that some 75,000 pounds had been imported up to the middle of August, 1957.

Imports come mainly from Colombia as bayberry wax or occasionally as "*cera de laurel*". South African imports come as bayberry wax or capeberry wax. A very small amount comes from Africa although higher prices may stimulate some activity. One American manufacturer (15a) produces a synthetic bayberry wax and could produce up to 500,000 pounds a year.

Myrica has been used for a few purposes besides its wax. The leaves of *Myrica cerifera* and *M. pensylvanica* are rather high in tannin; those of the first contain about 17 percent tannin. *Myrica Nagi* leaves have been used in India as tanning material for fancy leathers.

An essential oil has been extracted from the leaves of *Myrica cerifera*. It occurs in minute quantities, about 0.015 percent.

Medicinally *Myrica cerifera* has found some use. Youngken, in his "Textbook of Pharmacognosy", states that it has been used as "Astringent and tonic, stimulant to indolent ulcers, and as an ingredient in unofficial Composition Powder."

The principal use for bayberry wax is for making candles for the Christmas trade. The wax has a number of other uses, however. It is used in the making of soap and ointments and in various formulations for polishing leather; it is used in etching material and medicinals and in plastic arts, especially in moulding. It has been used in mixtures with paraffin in preparing an imbedding medium for plant tissue to be sectioned with a microtome.

The present study does not include all species of *Myrica* that may produce wax, but I believe it accounts for all American species. Chevalier in his monograph of *Myrica* (2) gives 27 species, and many varieties of the wax-bearing section *Cerophora*, for Africa. I have seen few of these, but those said to be sources of wax are included. Also are included a few others which I have seen with sufficient wax on the fruits to make them potential sources of wax. Chevalier gives fourteen species of the section as American.

A new monograph of *Myrica* is badly needed. The last one, by Chevalier, is long out of date and was prepared with inadequate material.

"Myrtle wax" has often been used as a name for bayberry wax. Warth (13) says that the name "has in the past been erroneously given to the myrica waxes", but destroys his statement by having used the term for a paragraph heading on a preceding page. There seems to be no reason not to use the name myrtle wax.

The bayberry wax that is collected and used locally and that gets into commerce comes from relatively few species. The two most important species may be *Myrica cerifera* L. and *Myrica cordifolia* L. *Myrica pensylvanica* Loisel, occasionally abundant in New England, was formerly important as a source of bayberry wax. Very little is now collected.

The genus *Myrica* is divided into two

subgenera. One subgenus, *Gale*, contains the sweet gales, which do not have a waxy coating on the fruit but may have a lustrous resinous substance on the surface. The second subgenus is *Morella*, the wax myrtles or bayberries, most or possibly all species of which have berries with a greater or lesser covering of wax, which often appears to be flakelike.

Chevalier, in his *Monographie des Myricacées*, divided the genus into three sections. The first of these was § *Morella* (Burm.) Chev. containing a half dozen or more Asian and Malasian species. The second was § *Faya* (Webb.) Chev., in which were included three species from Europe, Atlantic islands and North America. The section includes *Myrica inodora* and *M. californica* of our list. The third is § *Cerophora* (Raf.) Chev. which includes a large number of African and American species, most of the wax-bearing species. The subgenus *Gale*, mentioned previously, was accepted as a separate genus by Chevalier.

The Wax-bearing Species of Myrica

Myrica aethiopica L. This species is reported to be one source of capeberry wax in South Africa. Specimens from South Africa in the U. S. National Herbarium have some wax on the berries. *Myrica serrata* Lam., probably a synonym, has been mentioned as a source of wax. Some other species described from South Africa may also be included in this species.

Myrica californica Cham. & Schlecht. Specimens from Washington, Oregon, and California have abundant wax on the fruits. I have seen no record of the collection of wax from the species.

Myrica carolinensis Mill. Specimens of this species, which ranges from North Carolina southward, have wax on the fruits.

Myrica cerifera L. This is the species known as wax myrtle or candleberry. It is distributed from New Jersey to Arkansas and southward to Florida and Texas, the West Indies, Mexico, Central America and Panama. It is probably the species that occurs in Venezuela and Colombia and perhaps south to Bolivia. The genus *Myrica* is badly in need of a new systematic revision; however, the following species, which at one time or another have been given as a source of bayberry wax, or are potential sources, seem to be hardly more than variations of *Myrica cerifera*.

- *Myrica arguta* HBK. Reported as source of wax in Venezuela and Colombia.
- *Myrica caracasana* HBK. Reported as source of wax in Venezuela.
- *Myrica macrocarpa* HBK. Much like the others of this complex. I have found no record of wax extraction.
- *Myrica mexicana* Willd. A name commonly used for Mexican material. It is a synonym of *M. cerifera* L.
- *Myrica parvifolia* var. *confusa* Chev. Based on a specimen from Oaxaca, Mexico. It is most likely a synonym for *M. cerifera*.
- *Myrica polycarpa* HBK. Reported as the source of wax in Colombia.
- *Myrica xalapensis* HBK. Described from Mexico, it is almost certainly a synonym of *M. cerifera*. The specific name often appears in literature as "*jalapensis*".

The range of habitats and elevations which *Myrica cerifera*, as well as species here considered to be synonyms or variations, exhibits is rather great. *Myrica cerifera* occurs from bogs at sea level up to the páramo region at 3,600 meters or more in the Andes. In Mexico and Central America the species often forms or is part of dense thickets at elevations of 2,000 meters or less.

Myrica cordifolia L. One of the relatively few wax-bearing species of the genus in Africa. It is probably the

source of most of the myrica wax from Africa. The plant is said to be abundant near the sea in southern Africa. The wax is similar in composition and uses to that of *Myrica cerifera*.

Myrica heterophylla Raf. The species is distributed from New Jersey and New York south to Florida and Louisiana but is relatively uncommon. The berries may have been collected for the wax on them.

Myrica costata Rusby. The species is closely allied to *M. cerifera*, but may be distinct. It is known from the Bolivian Andes at an elevation of some 3,300 meters. The fruits have an abundant wax coating.

Myrica Funckii Chev. This species, described from Venezuela by Chevalier, belongs in the group of *Myrica* that bears wax. I have seen no material.

Myrica inodora Bartr. From the southeastern states of Florida, Georgia, Alabama, and Mississippi. It has some wax on the berries.

Myrica kilimandscharica Engl. An African species with wax on the fruits.

Myrica Lindeniana C. DC. A species of Mexico and Guatemala; it has wax on the fruits. It is closely allied to *M. cerifera*.

Myrica Macfarlanei Youngken. A hybrid of *M. cerifera* and *M. pensylvanica*. It has wax on the berries.

Myrica microcarpa Benth. Distributed at high elevations in Venezuela, Colombia, and Ecuador. The wax from this species possibly enters into that exported from Colombia. The plant is abundant at high elevations; it is also in the west Indies (Jamaica, Guadaloupe, Dominica), where it is native but seems not to have been used.

Myrica microstachya Krug & Urban. This species belongs to the group of wax-bearing species, but I do not know it. It was described from Jamaica.

Myrica parvifolia Benth. The species is not uncommon in Colombia and occurs in Ecuador. The berries have a wax covering, but the quantity of wax seems little. Chevalier gives five South American varieties of this species in his monograph.

Myrica Pavonis C. DC. Described from Peru, it is potentially wax-bearing. There is also a variety *glandulosa* Chev. from Peru. I do not know the species or the variety.

Myrica pensylvanica Loisel. The bayberry, or candleberry, ranges from Newfoundland and New Brunswick south to North Carolina and westward as far as Ohio. It is locally abundant in the hills and mountains of New England but is probably more abundant near the coast or on the coastal plain in its range.

Myrica Picardae Krug & Urban. A species described from Haiti. There is no record of wax collection, and little is known of the species. I have seen no specimens.

Myrica Pringlei Greenm. A little-known species distributed in Mexico, Guatemala, and El Salvador. The berries have a coating of wax, but I have seen no record of their collection for extracting the wax.

Myrica pubescens Willd. Distributed in Colombia, Ecuador, Peru, and Bolivia. The species resembles *M. cerifera* but is apparently distinct. The fruits have a sparse covering of wax or none. Chevalier describes five varieties of this species in his monograph.

Myrica punctata Griseb. A Cuban species which has wax on the berries. There is no record of its use for wax.

Myrica pusilla Raf. (Syn. *M. pumila* Michx., *Cerothamnus pumilus* (Michx.) Small). Distributed from Virginia through the southeastern United States. The berries have abundant wax, but there seems to be no record of their being collected for the wax.

Myrica quercifolia L. A South African species which may be wax-bearing.

Myrica reticulata Krug & Urban. This

species was described from Haiti. It is closely allied to *M. punctata* according to Chevalier. I have seen no specimens.

Myrica Shaferi Urban & Britton. A native of Cuba. The fruits bear wax, but there are few of them on the plants. There is no record of the wax being collected.

Literature Cited

1. Bennett, H. Commercial waxes. 1944.
2. Chevalier, A. Monographie des Myricacées. Mém. Soc. Sci. Nat. & Math. Cherbourg 32: 85–340. 1901.
3. Engler, A., in Engler & Prantl, Nat. Pflanzenf. 3[1]: 26–28. 1894.
4. Fernald, M. L. Gray's manual of botany, ed. 8, 523–525. 1950.
5. Gleason, H. A. New Britton & Brown illustrated flora. 2: 24. 1952.
6. Hutchinson, J., in Thiselton-Dyer, W. T., Flora Capensis 5: 561–572. 1925.
7. Olsson-Seffer, Pehr. Jalapa myrtle wax. Am. Rev. Trop. Agric. 1: 108. 1910.
8. Pérez-Arbeláez, Enrique. Plantas Útiles de Colombia. Ed. 3. 1956.
9. Rabak, Frank. Volatile oils of *Myrica cerifera* . . . . Midland Druggist and Pharmaceutical Rev. Unpaged reprint.
10. Standley, Paul C. Trees and shrubs of Mexico. Contrib. U. S. Nat. Herb. 23: 164. 1920.
11. Standley, Paul C. Flora of Costa Rica. Field Mus. Nat. Hist. Bot., ser. 28: 372. 1937.
12. Standley, Paul C., and Steyermark, J. A. Flora of Guatemala. Fieldiana Bot. 24(3): 348. 1952.
13. Warth, Albin H. The chemistry and technology of waxes. 1956.
14. Youngken, H. W. A textbook of pharmacognosy. 1948.
15. Letters from the following firms have given information on bayberry wax:
    a. International Wax Refining Company, Valley Stream, New York.
    b. D. Steengrafe & Co., Inc., New York.
    c. Clarence Morgan, Inc., Chicago.
    d. BTM Commodity Corp., New York.
    e. Strahl & Pitsch, Inc., New York.

Utilization Abstract

Spanish Broom. The Spanish or rush-leaved broom (*Spartium junceum*), a perennial legume, is found throughout the Mediterranean area. The young stems yield a fiber that has been used for textiles since ancient times. At the end of the last century, competition from textiles imported into France led to the abandoning of the *Spartium* industry. Interest in the fiber was renewed during World War II, and in 1946 three factories in France were equipped to extract the fiber, using a chemical retting process. The industry, which utilized natural stands of the plant, was geared at first to the production of mixed fabrics for clothing, sheets, table cloths, etc. When the importation of fibers into France returned to normal after 1946, the *Spartium* industry was forced to seek new uses for its product. Because of the great resistance to wear and decay possessed by Spanish broom fiber, it proved ideal for the manufacture of conveyor belts for use in a humid atmosphere. These belts have found a ready market in mines, coking plants, sugar refineries, etc. In 1952 a new factory was built in Aspiran for the extraction of *Spartium* fiber and the manufacture of cardboard from the stem residue. The factory is able to process 650 tons of stems per month. Cultivated Spanish broom yields up to 7% fiber, while wild plants yield only 4 to 5%. (P. Grignac, *Ann. Inst. Nat. de Rech. Agron. Sér. B. Ann. de l'Amélior. des Plantes 6(4): 413–479. 1956.*) (JWT)

BOOK REVIEWS

Grassland Seeds. Dr. W. A. Wheeler. D. Van Nostrand Company, Inc., Princeton, New Jersey. 768 pages. Illustrated. $12.50.

Doctor Wheeler, with the help of Dr. D. D. Hill and several others who know grassland seeds, tells in this book the fascinating story of the growing, processing, and marketing of the seeds used to produce meadows, pastures, and turf in the United States. He describes how a seed is formed in the parent plant, how it germinates and grows into a progeny plant which in turn produces seed of its kind. Building on this understanding, the author expands the single seed and plant into an historical account of the growing of crops of grassland seeds in the United States, and their harvesting, cleaning, and marketing. He then traces these seeds through processing and marketing channels until finally they are offered the consumer in such condition as may be required by federal and state seed laws. It is obviously a story of complexity, but it is told in such a way that even one who knows nothing about this economically important enterprise will find it informative and most interesting.

Though the book will be especially helpful to seed growers, seedsmen, county agents, soil conservation personnel, and vocational agriculture teachers, it will be quite useful to all who sow grassland seeds for meadows, pasture, and turf. Even those who are concerned with neither the business of grassland seeds nor the sowing of them but who only enjoy beautiful countrysides, lawns, and parks will find this book a liberal education in the grasslands that delight the eye.

The book is divided into three parts. The first deals with those phases of the grassland seed enterprise that are common to most or all kinds of grassland seeds. The second part covers the history, description, growing, and seed problems of each of almost 600 of the grassland seed crops of the United States. The third part is an appendix. It includes a glossary of terms, statistics on economic importance and yield of grassland seeds, and much other miscellaneous but pertinent information.

E. N. Fergus

Inhaltsstoffe und Prüfungsmethoden homöopathisch verwendeter Heilpflanzen. Herbert Schindler. iii + 231 pages. 1955. Aulendorf i. Württemberg (Germany): Editio Cantor. 24.80 DM.

This work treats in detail 115 medicinal plants, most of which are known and used here as well as in Germany. For each plant drug, the following points are taken up: botanical classification, range, part or parts used, preparations used in medicine, constituents, analysis, uses, and bibliography. The latter is quite elaborate; thus, for *Rhus toxicodendron* as an example, 54 literature citations appear (including those in the text). This same article covers 2½ pages of a quarto size 2-columned book and includes a photograph of the plant and graphic formulas of four compounds which in admixture compose "urushiol" (according to Symes and Dawson, 1953). The chemical treatment for each drug is complete and up-to-date, with valuable information on the chromatogram obtained from each drug. The book is composed of a long series of monographs on the drugs arranged in alphabetical sequence, as originally published in *Arzneimittel-Forschung*, published by the same firm as the book. The reprinting was preceded by very careful correction, revision, and supplementation. In this period, when so many plant drug materials are being submitted to a careful reexamination, this work merits inclusion in every library of phytochemistry, pharmacology, and therapeutics.

George M. Hocking